Changes in morphometric meander parameters identified on the Karoon River, Iran, using remote sensing data

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Abstract

River meander dynamics and mobility are important indicators of environmental change related to climate changes and anthropogenic activities at local and river basin scales. The aim of the present study is to identify morphological changes of the Karoon River in Iran using high accuracy maps and Landsat satellite images by analyses during the time period 1989-2008. In this study, 20 meandering reaches were analyzed over a 128-km-long river reach located in the middle part of the Karoon

River, Iran. Morphometric indicators such as: river width (*W*), meander neck length (*L*), axis length (*A*), radius of curvature (*R*), water flow length (*S*), and sinuosity of meander (*C*) were extracted for the identified meanders. The results of a paired *t*-test showed that river width (*W*) and meander neck length (*L*) have significantly changed during the study period (1989-2008), with an increase of +3.5 m for *W* and a decrease of 274 m for *L*. Spearman correlation analysis has shown that meander parameter changes are highly correlated to each other. The parameters that do not have significant correlation together are *C* with *W* and *L*, *W* and *L*, and *L* with *S* and *A*. During the period of the study, the flow length and river sinuosity decreased for the whole river reach, by 4.77 km and 0.11, respectively. Analysis of land use/ land cover categories (1989 and 2008) using the support vector machine (SVM) and kernel function method served as one of the tools for interpretation of the meander parameter changes. These changes can be attributed not only to LU/LC (riparian vegetation to agriculture area ratio) but also to dam construction in the upstream part of the river that leads to major hydrological regime and sediment transfer alteration. Sediment extraction may also be an important factor.

Keywords: human impact; land use; meander parameters changes; remote sensing; Karoon River

1. Introduction

River meanders are typical forms of river landscapes that are formed by various factors in fluvial systems (Hooke, 2013). This phenomenon represents hydrogeomorphological forms induced by lateral movement of the river (Dai et al.,

2008; Yousefi et al., 2015b). Meanders are among the important features that can change the morphology of floodplains (Lagasse et al., 2004; Güneralp and Rhoads, 2009; Güneralp et al., 2012). The behavior of meanders can be associated with major problems for human life, such as destroying residential and farming lands in the floodplain areas. River geomorphic properties are key factors to identifying environmental changes and particularly an association with changes in the river's marginal areas, such as different land cover types in the river sides and drainage basin (Dai et al., 2008). These morphological changes are attributed to changes of water and sediment load regime caused by climate, anthropogenic activities, or land use/land cover changes (Lagasse et al., 2004; Gordon and Meentemeyer, 2006; Cserkész-Nagy et al., 2010)

Floodplains and alluvial rivers have been historically and still are one of the most attractive places on Earth for human life and agriculture activities (Allan, 2004; Gordon and Meentemeyer, 2006; Boix-Fayos et al., 2007; James and Lecce, 2013). Land use and land cover (LULC) change is an indirect human impact that could have consequences on river morphology. The LULC change impacts on channel morphology could be considered at catchment or river reach scales (Kondolf et al., 2002; Liébault and Piégay, 2002; Belletti et al., 2016). Changes in the meander parameters can also be attributed to local management activities, as for instance the urbanization expansion, levees, riprap, dam, and road constructions (Nelson et al., 2013). In addition, meanders can naturally evolve and change shape over time even without human intervention (Brice, 1960; Hooke, 1984, 2013).

During the last 30 years, different studies on meandering rivers showed that water flow in the meander bend from centrifugal force can cause an intensive increase in water depth and helicoidal flow in the outer arc (Blanckaert, 2003; Frascati and Lanzoni, 2010; Chen and Tang, 2012;). Erosion and sedimentation processes have been observed at the front edge of the meander arcs (Frothingham and Rhoads, 2003; Rhoads et al., 2009; Riley and Rhoads, 2012). Bank erosion along the river will be exacerbated by human intervention in natural conditions and riparian land use changes (Gordon and Meentemeyer, 2006; Rutherfurd and Price, 2007; Yanan et al., 2011; Yousefi et al., 2015b). Bank erosion and channel migration can occur on different timescales (days, years, decades; Simon and Collison, 2002; Hooke, 2004; Ahmed and Fawzi, 2011; De Rose and Basher, 2011; Michalková et al., 2011). In recent decades, meandering river changes and deformation (narrowing, widening, incision) have been emphasized as of economic, social, and environmental importance (Kondolf, 1994; Allan, 2004; Rinaldi et al., 2005; Boix-Fayos et al., 2007; James and Lecce, 2013; Belletti et al., 2016). In relation to meander parameters and the factors influencing these changes, many studies have been done, especially outside of Iran (Yang et al., 1999; Timár, 2003; Chu et al., 2006; Wolfert and Maas, 2007; Ollero, 2010; Riley and Rhoads, 2012; Ziliani and Surian, 2012; Hooke, 2013; Nabegu, 2014; Liro, 2015; Yousefi et al., 2015b). Various classes and models of meander change have been suggested, but most of these methods are empirical, derived from case studies (Peixoto et al., 2009; Van De Wiel et al., 2011; Güneralp et al., 2012; Fuller et al., 2013; Pirot et al., 2014).

This study deals with meander morphology changes of the large Iranian Karoon River between two time horizons (1989 and 2008). Detection of the land use and land cover change during the study period, based on a support vector machine (SVM) algorithm classification with high accuracy, was key for better understanding of its effect on the river morphology. The classification of the styles of meander change (simple or combined) was identified. Land use and land cover (LULC) changes along the buffer zone of the study reach were recorded. The main aims of the present study are (i) spatio-temporal change of the alluvial part of the Karoon River (ii) effects of two main controlling factors (land use and gravel mining) on river geomorphology.

2. Study area

The Karoon River is located in the southwest of Iran; and from a hydro-energy point of view (dams in the upstream zone), it is the most important meandering Iranian river, with the highest discharge, length, and catchment area among all rivers in Iran. The Karoon River total length is about 950 km and the catchment area is about 67,500 km^2, with a population of 3.5 million people living in the catchment. The source of water for the Karoon River is Zagros Mountain with elevation of 4548 m asl, and in the downstream it joins with the Arvanrood River in Khoramshahr City, at an elevation of 12 m asl (Salarijazi, 2012). The Karoon catchment has a large range of elevations and it covers different types of climates. The Zagros Mountains (Aghajari, Mishan, and Bakhtyari) are geologically very heterogeneous with limestone, marly-limestone, marl, shale, sandstone, and conglomerate. The lowland areas include recent alluvial sediments. The long-term mean annual daily discharge at the Ahvaz gauging station over more than three decades (1972-2009) is 504 m^3s^{-1} and maximum annual

discharge is 2756 m^3s^{-1}. Dissolved sediment load is 10 g l^{-1}. In recent decades, many large dams were constructed for water storage, energy production, and irrigation purposes in this area (Salarijazi, 2012).

The studied river reach of the Karoon River is 128 km long (Fig. 1). Its upstream part is located close to one of the biggest dams in Iran, namely Gotvand Dam, built in 2003. The 180-m-high dam creates a reservoir volume of about 28.5million m^3. The downstream part of the river reach is located near Shoshtar City. A 3-km buffer area was defined along the study reach to monitor wider spatial changes (49,414 ha). It includes the cities of Shoshtar (187,337 inhabitants) and Gotvand (59,261 inhabitants).

3. Methodology

3.1. Data used

Figure 2 shows the flowchart of the methodology applied for clarifying morphological changes using remote sensed data for measuring bend parameters and amounts of LULC change along the 128-km channel length in the selected study reach. In this study, different Landsat images were used (Table 1). The geometric corrections with a nonparametric polynomial method were applied to the images according to 34 ground control points in stable parts of the vector road and stream layers. On stable sections of channelized river reaches and roads, 29 control points were selected. The total error of corrections was estimated according to root mean standard error (RMSE) and gives 0.34 in each pixel (30 m). Because no clouds were present at the time of the survey, no atmospheric correction was applied to the images. In the study reach, high

accuracy maps (1:10,000) produced by the Geological Surveys of Iran (GSI) have been used for identification of meander morphometric parameters. One of the most important points in this study is the spatial resolution (30 m) of images used for land use maps; these limits are a source of uncertainty in this study. Recent studies (Gualtieri and Cromp, 1999; Halder et al. 2011) demonstrated that support vector machine performs better than other algorithms to produce land cover maps, especially when a small number of training data are available. Obviously, the use of high-resolution images reduces the uncertainty in research, but accessibility to recent decades of data, freely downloadable, are the main reasons to use Landsat data in the current research. Moreover, many published papers focus on channel morphology changes that used Landsat datas which gives us more confidence (Chu et al., 2006; Peixoto et al., 2009; Ahmed and Fawzi, 2011; Thakur et al., 2012; Henshaw et al., 2013). As the river reach in both study dates is very important to geomorphological analysis and to the Landsat data (TM and ETM+) we cannot reach high spatial resolution in the present study; thus, the morphometric parameters have been extracted based on 1:10,000 scale maps.

3.2. Land use mapping in 1989 and 2008 and their change detection

For the method of land use and land cover mapping in the study area, training samples were prepared for each land use/land cover type (riparian vegetation, agriculture, residential, water body, and range land) using field surveys and a global positioning system (GPS). The training samples were divided into two parts based on a random partition algorithm (Table 2); one part for use in image classification, and a second class was used to evaluate the classification accuracy according to Perumal and

Bhaskaran (2010) and Srivastava et al. (2012). In order to obtain a robust set of training samples, especially for the first image (1989), the questionnaire responses to the question`'what was the land use type of your lands in 1989?' from 118 local native people were used (100 farmers and 18 persons that live in Shoshtar and Gotvand cities). For the land use/land cover map of the study area the support vector machine (SVM) algorithm was used, and the kernel function method was developed for each image. The radial basis function (RBF) was used as the kernel function; and λin the kernel function represents a value of 0.167, and the value of the penalty parameter achieved 250. A pyramid level was automatically selected as 100 in ENVI 4.7 software (Yousefi et al., 2011, 2015a). In this study, detection of the land use and land cover changes between 1989 and 2008 were cross-matched and compared using ENVI 4.7 software where the post-classification method based on classified images for both dates was applied (Xu and Gong, 2007; Srivastava et al., 2009, 2012; Yousefi et al., 2011).

3.3. Meander parameters

For considering meander parameters, channel centerlines and bank lines of the study river reach were digitized and divided into 20 meander loops. Meander loop changes have been identified according to Hooke´s (1984, 2013) models of meander changes. In this model the meander changes have been classified based on visual and spatial changes. In the study simple or combined types of meander changes (translation, rotation, extension, expansion, cutoff, redevelopment, lateral movement, irregular changes) are presented (Fig. 3B).

The specific meander parameters represent axis length (*A*), meander neck length (*L*), river width (*W*), radius of curvature (*R*), water flow length (*S*), and sinuosity (*C*; Fig. 3A). Axis length is the longest distance between the internal arc and the meander neck. Meander neck is the lowest distance between two meander loops. Water flow length is the length of water between two meander apexes. Radius of curvature is the radius of the maximum interior circle in a meander loop, river width (*W*) is an average of five cross sections (the lowest distances between river banks) in the meander curve (Hooke, 2013). Sinuosity (*C*) was calculated using the following equation:

$$C = S/L \quad (1)$$

Morphometric parameters for all meander loops in 1989 and 2008 were measured by measurement tools in ArcGIS 10.2. and AUTOCAD 2009.

The statistical analysis of paired sample *T*-tests and Pearson correlations to study the variation of meander parameters and their correlation between 1989 and 2008 was used as the final step.

4. Results

The results of two main types of analysis are presented: first the land use and land cover changes in the buffer zone of the study river reach; and second, the detailed changes of meander parameters between two dates.

4.1. LULC changes

The land use and land cover maps in 1989 and 2008 were prepared using the SVM algorithm and kernel function method (Fig. 4). The overall accuracy and K

coefficient of produced LULC maps were calculated and presented in Table 3. The classification accuracy of the LULC map created for 1989 with overall accuracy of 88.18% and K coefficient of 0.7879 is lower than the LULC map created for 2008 with overall accuracy of 94.51% and K coefficient of 0.8937. The results showed that the areas of water body, riparian vegetation, and rangeland have decreased over the study period (Fig. 5). In contrast, agriculture and residential land cover types have increased. However, the LULC maps with detected changes (Fig. 6) showed that 24% of the study area has been changed (120 km^2), and water body and riparian vegetation areas had the highest changes in the study area, with 54% and 52%, respectively (Table 4).

4.2. Meander parameter changes and statistical analysis

Channel centerlines of the study reach were digitized and 20 meander loops were selected for two time horizons (Fig. 7). Morphometric parameters for all meander loops in 1989 and 2008 were measured, and the morphological change of meander loops were calculated (Table 5). Mean values of the river width between 1989 and 2008 indicate a decreasing trend of the river width. On the contrary, the sinuosity (*C*) during the two decades increased. Results of meander morphological variables show that the standard deviation (*SD*) of *R* and *S* in 1989 is higher than in 2008. On the other hand, the *SD* of *W, A, L,* and *C* in 2008 is higher than 1989. These results show that the variability of river width (*W*) and water flow length (*S*) among 20 study meanders in 1989 are more than the 2008 values.

Results of meander morphological change show that in the study reach three types of meander change (simple, double, and triple). Several meander (number 4, 5,

7, 15, 18, 20) loops with the greatest morphological changes represent combinations of double and triple types of change (Fig. 8). In addition, in three meander loops cutoff and redevelopment of meanders have been observed (meanders 9, 10, and 11); all of these meanders are located between two sand extraction mines. Besides, more than half (11) of all studied meanders were assigned simple change represented by translation, rotation, lateral movement, expansion, or irregular changes.

According to paired samples *T*-test (Table 6) for studying the variation of meander parameters, a significant change within 5% confidence level between the two dates for the meander neck length (*L*) and the meander width (*W*). In contrast, no significant difference was observed for radius of curvature (R), water flow length (*S*), sinuosity (*C*), and meander axis length (*A*) between the mentioned dates.

The results of the Pearson correlation between meander parameter changes are given in Table 7. Table 7 shows that a significant correlation between sinuosity changes (*C*) and radius of curvature (*R*), water flow length (*S*), and axis length (*L*) changes at confidence level of 5%, 1%, and 1%, respectively. Significant correlation was also found between change in the radius of curvature (R) with water flow length (*L*), axis length (*A*), meander neck length, and river width changes at a significance level of 5%, 1%, 1%, and 1%, respectively. In addition, a significant correlation between changes in the river width (*W*), water flow length (*L*), and axis length (*A*) changes at a confidence level of 1%. Also water flow length (*L*) has a significant correlation at the 1% level with axis length (*A*) of the meander (Table 7).

5. Discussion

Morphological changes in river systems relate together like a chain (Lagasse et al., 2004). Recorded changes in radius of curvature (*R*) caused by enlargement of the internal arc led to an increase of water flow length (*S*) and enlargement of meander neck length (*L*). The axis length (*A*) increased by this process, too. According to the sinuosity coefficient (*C*), increasing values of morphometric parameters (*S* and *L*) apparently increased the sinuosity of meander in 2008. The river width (*W*) changes are inversely related to the changes of water flow length (S) and axis length (*A*) of the meander. The axis length of meanders represents the transverse fluctuations. Indeed, the consequence of factors such as geological type of the river bed, hydrological conditions of the river, and alteration of the river bed. If meander neck length (*L*) remains constant over time, the radius of curvature (*R*) will decrease and sinuosity (*C*) of meanders increases (Crosato, 2008; Heo et al., 2009). In general, results show a direct relationship between radius of curvature changes and changes of sinuosity, meander neck length, water flow length, and axis length of meander (Table 7).

In the study area, the riparian vegetation, water body, and range land type areas have decreased by 262, 351, and 214 ha, respectively. On the other hand, agricultural and residential areas increased by 304 ha and 522 ha, respectively. Range lands, riparian vegetation, and floodplain areas are the property of the government institution of the National lands in Iran. Because of the low levels of land protection in National lands, the stakeholders every year pushed to change the types of these lands to types like residential or agricultural because of financial attractiveness.

In parts of the river where agriculture comes near to the river banks, river width (*W*) was reduced (Fig. 9). According to Yanan et al. (2011), when river width is reducing and a cutoff occurs, the river slope is increasing, i.e., the same amount of water discharge is forced to flow down the river more quickly in the smaller, steeper, and narrowed section. Increase of water velocity caused an increase of stream power and greater bank erosion that resulted in an increase in water flow length (*S*) and axis length (*A*) of meanders in our studied reach.

According to field surveys and assessment of land use maps in 1989 and 2008, the study area, particularly in the river margins (i.e., 3-km buffer zone along the river length) has been interrupted by human activities such as irrigation channels, residential land sprawl, and sand mining. Human impact as a crucial factor of river morphology changes is documented in several papers (Liébault and Piégay, 2002; Zaimes et al., 2004; James and Lecce, 2013; Yousefi et al., 2015; Belletti et al., 2016). This activity was observed with greater intensity in meanders 8 to 13 (Fig. 9), where destruction of riparian area and conversion to agricultural land has been most observed. The high quality of the soils in the upstream part and particularly the alluvial banks and the riparian covers are the main reasons that encourage the local people that live in the marginal area to plough the land and change the land to farming area near the river banks. According to Güneralp et al. (2012), plowing the land and destroying the natural vegetation of the river cause soil loss and therefore degradation of the meander outer arc. Riparian vegetation is one of the most important factors that controls bank erosion as the main process of river migration (Timár, 2003; Cabezas et al., 2008; Ollero, 2010; Engel and Rhoads, 2012). Ahmed and Fawzi (2011a) in a

study of the Nile River reported that in agricultural land bank erosion and river widening is more than in riparian vegetation lands, similar to our results.

Sand extraction on the river floodplain to obtain sand for urban and dam construction, changes the waterway, soil stability, and cohesion by removing organic matter. Removal of cohesive components such as clay and organic material (wood, grass, and roots) makes the soil more erodible (Kondolf, 1994; Rinaldi et al., 2005; Cserkész-Nagy et al., 2010; Martín-Vide et al., 2010; Gutierrez et al., 2014; Smith et al., 2016). In the study site four active sand mining factories. Meanders that are near the extraction sites have anabranch shapes and high changes as a consequence of river bed disturbance (Latapie et al., 2014). Meander number 20 is affected by mines where sand was extracted for dam construction and meanders 9, 10, and 11 are affected by mines that were worked for building construction. According to the meander change classification method, meander number 20 has the triple combination type of extension, translation, and rotation processes; while in meanders number 9, 10, and 11 the cutoff process has occurred and then meanders have redeveloped. Dai et al. (2008) have reported the effect of uncontrolled sand extraction in the Pearl River in China over the last two decades; the abnormal changes in meanders near the sand mines demonstrated in this study are similar to those results. Brunier et al. (2014) also mentioned the effects of sand extraction on increasing flow paths in the Mekong delta in Vietnam.

The Gotvand Dam is one of the largest dams in Iran and is the last downstream dam on the Karoon River. Gotvand Dam has some impact on Karoon discharge and sediment load as, before dam construction, the average daily discharge (1972-2002)

315 was 534 m^3s^{-1}, but after the dam was constructed the average daily discharge (2003-
316 2009) decreased to 490 m^3s^{-1}. Average daily suspended sediment load for before and
317 after dam construction were 16.36 and 9.12 g l^{-1}, respectively. Results of meander
318 change classifications show that most of the study meanders have two types of
319 change, simple and double (16 meanders), and in most of them the meander has a
320 simple combination of change in its form; this could be because of the controlling role
321 of Gotvand Dam. In addition, in the study area three cutoffs located between two
322 mining sites appeared during the study period. Gravel mining in some cases changes
323 the structure and form of the river bed and consequently water flow changes the
324 direction of the channel to more erodible sides (James, 1991; Liébault and Piégay,
325 2002; Batalla, 2003; Rinaldi et al., 2005; Martín-Vide et al., 2010; Belletti et al., 2016
326). We suggest that further studies can be done on the rate of changes and monitoring
327 and evaluation in the area.
328

329 **6. Conclusion**

330 An understanding of fluvial system response over recent decades is essential
331 knowledge to assess and predict effects of human disturbances on watershed areas and
332 fluvial systems (Latapie et al., 2014). The main aim of the current study was to
333 investigate and identify morphological changes in a part of the Karoon River over the
334 period 1989 to 2008 and the possible effects of land use on morphological changes
335 using remote sensing data. During the study, the river flow length and river sinuosity
336 decreased for the that river reach by 4.77 km and 0.11, respectively. This decrease is
337 mainly because of cutoffs in three meanders which are all located between two sand

extraction sites. Gravel mining has direct effects on river morphology; in mining sites by extracting sand and gravel, the flow of the river and the power of the water always find the easier way to flow. Land use maps were prepared using the SVM algorithm; and results of land use change detection showed that during two decades, 1928 ha of water body and riparian vegetation were converted to agricultural lands. Gotvand Dam has a controlling role on the sediment load in the study area; also this dam decreased the average daily discharge of downstream by about 44 m^3s^{-1}. By decreasing flow discharge, the power of flow decreased and high intensity floods were controlled by the constructed dams; and as a consequence, the river form has adjusted in most of the meander. However, in meanders that have been affected by sand extraction, this is not true (Gordon and Meentemeyer, 2006; Dai et al., 2008; Lorenz et al., 2009; Ma et al., 2012; Csiki and Rhoads, 2014; Grenfell et al., 2014; Yousefi et al., 2015b). Finally we can say that sand mining has a significant role in decreasing the flow length by increasing the probability of cutoff events; dam building (discharge controlling) and land use change (removal of the riparian vegetation) have an important role in decreasing channel width in the study reach of the Karoon River.

Exploration of the meander parameters can help to predict future trends in river morphology and meander evolution. Understanding the changing meander parameters could help to achieve better river management and mitigation of the damages associated with these changes.

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References

Ahmed, A. a., Fawzi, A., 2011. Meandering and bank erosion of the River Nile and its environmental impact on the area between Sohag and El-Minia, Egypt. Arabian Journal of Geosciences 4, 1–11.

Allan, J.D., 2004. Landscapes and riverscapes: the influence of land use on stream ecosystems. Annual review of ecology, evolution, and systematics. Annual Review of Ecology Evolution and Systematics 35, 257-284.

Batalla, R.J., 2003. Sediment deficit in rivers caused by dams and instream gravel mining: A review with examples from NE Spain. Cuaternario y geomorfología: Revista de la Sociedad Española de Geomorfología y Asociación Española para el Estudio del Cuaternario 17(3), 79-91.

Belletti, B., Nardi, L. and Rinaldi, M., 2016. Diagnosing problems induced by past gravel mining and other disturbances in Southern European rivers: the Magra River, Italy. Aquatic Sciences 78(1), 107-119.

Blanckaert, K., 2003. Nonlinear modeling of mean flow redistribution in curved open channels. Water Resources Resarch 39, 1–14.

Boix-Fayos, C., Barberá, G., López-Bermúdez, F. and Castillo, V., 2007. Effects of check dams, reforestation and land-use changes on river channel morphology:

384 Case study of the Rogativa catchment (Murcia, Spain). Geomorphology 91(1),
385 103-123.

386 Brice, J.C., 1960. Index for description of channel braiding. Geological Society of
387 America Bulletin 71, 1833.

388 Brunier, G., Anthony, E.J., Goichot, M., Provansal, M., Dussouillez, P., 2014. Recent
389 morphological changes in the Mekong and Bassac river channels, Mekong delta:
390 The marked impact of river-bed mining and implications for delta destabilisation.
391 Geomorphology 224, 177–191.

392 Cabezas, a., Comin, F. a., Begueria, S., Trabucchi, M., 2008. Hydrologic and land-
393 use change influence landscape diversity in the Ebro River (NE Spain).
394 Hydrological Earth System Sciences and Discussion 5, 2759–2789.

395 Camporeale, C., Ridolfi, L., 2010. Interplay among river meandering, discharge
396 stochasticity and riparian vegetation. Journal of Hydrology 382, 138–144.

397 Chen, D., Tang, C., 2012. Evaluating secondary flows in the evolution of sine-
398 generated meanders. Geomorphology 163-164, 37–44.

399 Chu, Z.X., Sun, X.G., Zhai, S.K., Xu, K.H., 2006. Changing pattern of
400 accretion/erosion of the modern Yellow River (Huanghe) subaerial delta, China:
401 Based on remote sensing images. Marine Geology 227, 13–30.

402 Constantine, C.R., Dunne, T., Hanson, G.J., 2009. Examining the physical meaning of
403 the bank erosion coefficient used in meander migration modeling.
404 Geomorphology 106, 242–252.

405 Crosato, A., 2008. Analysis and modelling of river meandering. IOS Press,

406 Amsterdam, 251 pp.

407 Cserkész-Nagy, Á., Tóth, T., Vajk, Ö., Sztanó, O., 2010. Erosional scours and
408 meander development in response to river engineering: Middle Tisza region,
409 Hungary. Proceedings of the Geologists' Association 121, 238–247.

410 Csiki, S.J.C., Rhoads, B.L., 2014. Influence of four run-of-river dams on channel
411 morphology and sediment characteristics in Illinois, USA. Geomorphology 206,
412 215–229.

413 Dai, S.B., Yang, S.L., Cai, a. M., 2008. Impacts of dams on the sediment flux of the
414 Pearl River, southern China. Catena 76, 36–43.

415 De Rose, R.C., Basher, L.R., 2011. Measurement of river bank and cliff erosion from
416 sequential LIDAR and historical aerial photography. Geomorphology 126, 132–
417 147.

418 Engel, F.L., Rhoads, B.L., 2012. Interaction among mean flow, turbulence, bed
419 morphology, bank failures and channel planform in an evolving compound
420 meander loop. Geomorphology 163-164, 70–83.

421 Frascati, A., Lanzoni, S., 2010. Long-term river meandering as a part of chaotic
422 dynamics? A contribution from mathematical modelling. Earth Surface Process
423 and Landforms 35, 791–802.

424 Frothingham, K.M., Rhoads, B.L., 2003. Three-dimensional flow structure and
425 channel change in an asymmetrical compound meander loop, Embarras River,
426 Illinois. Earth Surface Process and Landforms 28, 625–644.

427 Fuller, I.C., Reid, H.E., Brierley, G.J., 2013. Methods in Geomorphology:

Investigating River Channel Form, Treatise on Geomorphology. Elsevier Ltd.

Giriraj, A., Irfan-Ullah, M., Murthy, M.S.R., Beierkuhnlein, C., 2008. Modelling spatial and temporal forest cover change patterns (1973-2020): A case study from South Western Ghats (India). Sensors 8, 6132–6153.

Gordon, E., Meentemeyer, R.K., 2006. Effects of dam operation and land use on stream channel morphology and riparian vegetation. Geomorphology 82, 412–429.

Grenfell, M.C., Nicholas, a. P., Aalto, R., 2014. Mediative adjustment of river dynamics: The role of chute channels in tropical sand-bed meandering rivers. Sedimentary Geology 301, 93–106.

Güneralp, I., Rhoads, B.L., 2009. Empirical analysis of the planform curvature-migration relation of meandering rivers. Water Resources Research 45, 1–15.

Güneralp, I., Abad, J.D., Zolezzi, G., Hooke, J., 2012. Advances and challenges in meandering channels research. Geomorphology 163-164, 1–9.

Gutierrez, R.R., Abad, J.D., Choi, M., Montoro, H., 2014. Characterization of confluences in free meandering rivers of the Amazon basin. Geomorphology 220, 1–14.

Henshaw, A.J., Gurnell, A.M., Bertoldi, W., Drake, N. a., 2013. An assessment of the degree to which Landsat TM data can support the assessment of fluvial dynamics, as revealed by changes in vegetation extent and channel position, along a large river. Geomorphology 202, 74–85.

Heo, J., Duc, T.A., Cho, H.S., Choi, S.U., 2009. Characterization and prediction of

meandering channel migration in the GIS environment: A case study of the Sabine River in the USA. Environmental Monitoring and Assessment 152, 155–165.

Hooke, J., 1984. Changes in river meanders – a review of techniques and results of analyses. Progress in Physica Geography 8, 473–508.

Hooke, J.M., 2004. Cutoffs galore!: Occurrence and causes of multiple cutoffs on a meandering river. Geomorphology 61, 225–238.

Hooke, J. M., 2013. River Meandering. In E. Wohl, & J. Schroder (Eds.), Treatise on Geomorphology 9, 260-288

Howard, A.D., 2009. How to make a meandering river. Proceeding of the National Academy of Sciences of the United States of America 106, 17245–17246.

James, L. Lecce, S., 2013. Impacts of land-use and land-cover change on river systems. Shroder, Jr., J. (Ed. in chief), Wohl, E.(Eds.), Treatise on Geomorphology 9, 768-793.

James, L.A., 1991. Incision and morphologic evolution of an alluvial channel recovering from hydraulic mining sediment. Geological Society of America Bulletin 103(6), 723-736.

Kondolf, G.M., 1994. Geomorphic and environmental effects of instream gravel mining. Landscape and Urban Planning 28(2), 225-243.

Kondolf, G., Piégay, H. and Landon, N., 2002. Channel response to increased and decreased bedload supply from land use change: contrasts between two catchments. Geomorphology 45(1), 35-51.

Lagasse, P.F., Zevenbergen, L.W., Spitz, W.J., Thorne, C.R., Associates, A., Collins, F., 2004. Methodology for Predicting Channel Migration, Rivers. NCHRP Web-Only Document 67 (Project 24-16)

Latapie, a., Camenen, B., Rodrigues, S., Paquier, a., Bouchard, J.P., Moatar, F., 2014. Assessing channel response of a long river influenced by human disturbance. Catena 121, 1–12.

Liébault, F. and Piégay, H., 2002. Causes of 20th century channel narrowing in mountain and piedmont rivers of southeastern France. Earth Surface Processes and Landforms 27(4), 425-444.

Liro, M., 2015. Gravel-bed channel changes upstream of a reservoir: The case of the Dunajec River upstream of the Czorsztyn Reservoir, southern Poland. Geomorphology 228, 694–702.

Lofthouse, C., Robert, A., 2008. Riffle-pool sequences and meander morphology. Geomorphology 99, 214–223.

Lorenz, A.W., Jähnig, S.C., Hering, D., 2009. Re-meandering german lowland streams: Qualitative and quantitative effects of restoration measures on hydromorphology and macroinvertebrates. Environmental Management 44, 745–754.

Ma, Y., Huang, H.Q., Nanson, G.C., Li, Y., Yao, W., 2012. Channel adjustments in response to the operation of large dams: The upper reach of the lower Yellow River. Geomorphology 147-148, 35–48.

Martín-Vide, J., Ferrer-Boix, C. and Ollero, A., 2010. Incision due to gravel mining:

494 Modeling a case study from the Gállego River, Spain. Geomorphology 117(3),
495 261-271.

496 Michalková, M., Piégay, H., Kondolf, G.M. and Greco, S.E., 2011. Lateral erosion of
497 the Sacramento River, California (1942-1999), and responses of channel and
498 floodplain lake to human influences. Earth Surface Processes and Landforms
499 36(2), 257-272.

500 Nabegu, A.B., 2014. Impact of Urbanization on Channel Morphology: Some
501 Comments. IOSR Journal of Environmental Science, Toxicology and Food
502 Technology (IOSR-JESTFT) 8, 40–45.

503 Nardi, L., Rinaldi, M., Solari, L., 2012. An experimental investigation on mass
504 failures occurring in a riverbank composed of sandy gravel. Geomorphology 163-
505 164, 56–69.

506 Nelson, N.C., Erwin, S.O., Schmidt, J.C., 2013. Spatial and temporal patterns in
507 channel change on the Snake River downstream from Jackson Lake dam,
508 Wyoming. Geomorphology 200, 132–142.

509 Ollero, A., 2010. Channel changes and floodplain management in the meandering
510 middle Ebro River, Spain. Geomorphology 117, 247–260.

511 Peixoto, J.M. a, Nelson, B.W., Wittmann, F., 2009. Spatial and temporal dynamics of
512 river channel migration and vegetation in central Amazonian white-water
513 floodplains by remote-sensing techniques. Remote Sensing and Environment 113,
514 2258–2266.

515 Perucca, E., Camporeale, C., Ridolfi, L., 2006. Influence of river meandering

dynamics on riparian vegetation pattern formation. Journal of Geophysical Researche Biogeosciences 111, 1–9.

Perumal, K., Bhaskaran, R., 2010. Supervised classification performance of multispectral images. Journal of Computing 2, 124–129.

Pirot, G., Straubhaar, J., Renard, P., 2014. Simulation of braided river elevation model time series with multiple-point statistics. Geomorphology 214, 148–156.

Posner, A.J., Duan, J.G., 2012. Simulating river meandering processes using stochastic bank erosion coefficient. Geomorphology 163-164, 26–36.

Rhoads, B.L., Riley, J.D., Mayer, D.R., 2009. Response of bed morphology and bed material texture to hydrological conditions at an asymmetrical stream confluence. Geomorphology 109, 161–173.

Riley, J.D., Rhoads, B.L., 2012. Flow structure and channel morphology at a natural confluent meander bend. Geomorphology 163-164, 84–98.

Rinaldi, M., Wyżga, B. and Surian, N., 2005. Sediment mining in alluvial channels: physical effects and management perspectives. River Research and Applications 21(7), 805-828.

Rusnák, M., Lehotský, M., 2013. Time-focused investigation of river channel morphological changes due to extreme floods. Zeitschrift für Geomorphologie 58, 2, 251-266.

Rutherfurd, I., Price, P., 2007. Management on Stream Erosion, in: The Influence of Riparian Managment on Stream Erosion. Land & Water Australia, Canberra, pp. 86–116.

538 Salarijazi, M., 2012. Trend and change-point detection for the annual stream-flow
539 series of the Karun River at the Ahvaz hydrometric station. African Journal of
540 Agricultural Research 7, 4540–4552.

541 Seker, D.Z., Kaya, S., Musaoglu, N., Kabdasli, S., Yuasa, A., Duran, Z., 2005.
542 Investigation of meandering in Filyos River by means of satellite sensor data.
543 Hydrological Processes 19, 1497–1508.

544 Simon, A. and Collison, A.J., 2002. Quantifying the mechanical and hydrologic
545 effects of riparian vegetation on streambank stability. Earth Surface Processes
546 and Landforms 27(5), 527-546.

547 Smith, C. Bowie, M.H., Hahner, J.L., Boyer, S., Kim, H.T., Abbott, M., Rhodes, S.,
548 Sharp, D., Dickinson, N., 2016. Punakaiki Coastal Restoration Project: A case
549 study for a consultative and multidisciplinary approach in selecting indicators of
550 restoration success for a sand mining closure site, West Coast, New Zealand.
551 Catena 136, 91-103.

552 Solín, Ľ., Feranec, J., Nováček, J., 2011. Land cover changes in small catchments in
553 Slovakia during 1990-2006 and their effects on frequency of flood events.
554 Natural Hazards 56, 195-214.

555 Srivastava, P.K., Majumdar, T.J., Bhattacharya, A.K., 2009. Surface temperature
556 estimation in Singhbhum Shear Zone of India using Landsat-7 ETM + thermal
557 infrared data. Advances in Space Research 43, 1563–1574.

558 Srivastava, P.K., Han, D., Rico-Ramirez, M. a., Bray, M., Islam, T., 2012. Selection
559 of classification techniques for land use/land cover change investigation.

560 Advances in Space Research 50, 1250–1265.

561 Thakur, P.K., Laha, C., Aggarwal, S.P., 2012. River bank erosion hazard study of
562 river Ganga, upstream of Farakka barrage using remote sensing and GIS. Natural
563 Hazards 61, 967–987.

564 Timár, G., 2003. Controls on channel sinuosity changes: A case study of the Tisza
565 River, the Great Hungarian Plain. Quaternary Science Reviews 22, 2199–2207.

566 Van De Wiel, M.J., Coulthard, T.J., Macklin, M.G., Lewin, J., 2011. Modelling the
567 response of river systems to environmental change: Progress, problems and
568 prospects for palaeo-environmental reconstructions. Earth Science Review 104,
569 167–185.

570 Wolfert, H.P., Maas, G.J., 2007. Downstream changes of meandering styles in the
571 lower reaches of the River Vecht, the Netherlands. Geologie en Mijnbouw 86,
572 257–271.

573 Xu, B., Gong, P., 2007. Land-use / Land-cover Classification with Multispectral and
574 Hyperspectral EO-1 Data 73, 955–965.

575 Yanan, L., Yuliang, Q., Yue, Z., 2011. Dynamic Monitoring and Driving Force
576 Analysis on Rivers and Lakes in Zhuhai City Using Remote Sensing
577 Technologies. Procedia Environmental Sciences 10, 2677–2683.

578 Yang, X., Damen, M.C.., van Zuidam, R. a, 1999. Satellite remote sensing and GIS
579 for the analysis of channel migration changes in the active Yellow River Delta,
580 China. Internaional Journal of Applied Earth Observation and Geoinformation 1,
581 146–157.

582 Yousefi, S., Moradi, H.R., Hosseini, S.H., Mirzaee, S., 2011. Land use change
583 detection using Landsat TM and ETM+ satellite image over Marivan. Journal of
584 RS and GIS for Natural Resources (Journal of Applied RS and GIS Techniques in
585 Natural Resources Science) 2, 97–105.

586 Yousefi, S., Khatami, R., Mountrakis, G., Mirzaee, S., Pourghasemi, H.R., Tazeh, M.,
587 2015a. Accuracy assessment of land cover / land use classifiers in dry and humid
588 areas of Iran. Environmental Monitoring and Assessment 187 (10):
589 641.doi:10.1007/s10661-015-4847-1

590 Yousefi, S., Moradi, H.R., Tevari, A., Vafakhah, M., 2015b. Monitoring of fluvial
591 systems using RS and GIS (Case study: Talar River, Iran). Journal of Selçuk
592 University Natural and Applied Science 4, 60–72.

593 Zaimes, G., Schultz, R., Isenhart, T., 2004. Stream bank erosion adjacent to riparian
594 forest buffers, row-crop fields, and continuously-grazed pastures along Bear
595 Creek in central Iowa. Journal of Soil Water Conservation 59, 19–27.

596 Zhang, B., Ai, N., Huang, Z., Yi, C., Qin, F., 2008. Meanders of the Jialing River in
597 China: Morphology and formation. Chinese Science Bulletin 53, 267–281.

598 Zhang, Y., Wang, P., Wu, B., Hou, S., 2015. An experimental study of fluvial
599 processes at asymmetrical river confluences with hyperconcentrated tributary
600 flows. Geomorphology 230, 26–36.

601 Ziliani, L., Surian, N., 2012. Evolutionary trajectory of channel morphology and
602 controlling factors in a large gravel-bed river. Geomorphology 173-174, 104–
603 117.

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Figures caption

Fig. 1. Location of study area in Khozestan Province, Iran.

Fig. 2. Flow chart of the used methodology based on geometric correction of remote sensed data, land use/land cover, and river features evaluation (meander parameters).

Fig. 3. (A) Morphometric parameters of study meanders: axis length (*A*), meander neck length (*L*), river width (*W*), radius curvature (*R*), water flow length (*S*). (B) Model of meander change based on Hooke (1984).

Fig. 4. Land use maps in 1989 and 2008.

Fig. 5. Areal changes in five land use/land cover types during the study period.

Fig. 6. Detection of land use/land cover changes during the study period.

Fig. 7. Study meanders and centerlines of the study river reach with marked areas of sand mining.

Fig. 8. Morphological change of the most variable meanders in the study river reach.

Fig. 9. Morphological change of the most variable meanders and land use/land cover change.

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Table 1

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Data used in the study area

Data	Date	Scale/resolution	Provider	Discharge $m^3 s^{-1}$
TM	23/May/1989	30*30 meters	USGS	569
ETM+	5/June/2008	30*30 meters	USGS	325
Topography map	25/March/2001	1:25,000	National Cartographic Center of Iran (NCC)	550
Geology map	10/March/2008	1:100,000	Geological Surveys of Iran (GSI)	413
Active channel plan	12/June/1989	1:10000	Geological Surveys of Iran (GSI)	518
Active channel plan	12/Juley/2008	1:10000	Geological Surveys of Iran (GSI)	301

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Table 2

Training sample characteristics

Land use/land cover types	Training sample				
	Number of training samples	Classification (ha)	Evaluation (ha)	Classification (pixels)	Evaluation (pixels)
Riparian vegetation	86	41.48	17.26	460	192
Agriculture	207	469.4	137.67	5215	1528
Residential	48	6.16	1.87	68	20
Water body	39	6.3	1.7	70	18
Range land	112	145.7	40.3	1618	447

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Table 3

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679 Coefficient classification accuracy of the produced land use/land cover maps based on using ground control points

Year	Overall accuracy (%)	Kappa coefficient
1989	88.18	0.7876
2008	94.51	0.8937

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Table 4

Detection of the land use and land cover changes during the study period

Land use/land cover changes between 1989 and 2008	Area (ha)	Percent
Agriculture no change	26314.8	82.64
Agriculture to Range land	3375.1	10.6
Agriculture to Residential	837.2	2.63
Agriculture to Riparian vegetation	837.67	2.63
Agriculture to Water body	479.1	1.5
Range land no change	7107.9	65.39
Range land to Agriculture	3477.2	31.99
Range land to Residential	284.4	2.62
Residential no Change	1570.9	96.05
Residential to Water body	64.6	3.95
Riparian vegetation no change	1448.4	47.9
Riparian vegetation to Agriculture	1334.04	44.12
Riparian vegetation to Residential	35.9	1.19
Riparian vegetation to Water body	205.2	6.79
Water body no change	920.8	45.12
Water body to Agriculture	594.6	29.13
Water body to Residential	124.9	6.12
Water body to Riparian vegetation	400.7	19.63

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Table 5

Meander parameters as river width (*W*), radius curvature (*R*), axis length (*A*), meander neck length (*L*), water flow length (*S*), and sinuosity (*C*) measured on the study river reach in two time horizons (1989 and 2008) and morphological change of meander loops (SD – standard deviation)

	1989						2008						Morphological change (1989-2008)	
Number	W (km)	R (km)	A (km)	L (km)	S (km)	C	W(km)	R (km)	A (km)	L (km)	S (km)	C	Type of change	Description
1	0.253	1.6	4.13	5.44	10.31	1.89	0.173	1.85	3.94	5.1	10.42	2.04	Simple	Translation
2	0.217	1.41	3.2	5.4	8.31	1.54	0.183	1.23	3.17	5.58	8.51	1.53	Simple	Rotation
3	0.231	4.47	3.23	7.87	13.23	1.68	0.172	4.65	3.08	8.43	14.09	1.67	Simple	Irregular Changes
4	0.152	1.24	2.1	2.76	5.63	2.04	0.112	1.36	2.14	2.3	6.23	2.71	Double	Extension and Rotation
5	0.214	1.79	2.87	2.94	6.39	2.17	0.171	2.05	2.57	2.49	7.51	3.02	Double	Rotation and Expansion
6	0.218	0.36	1.82	3.53	4.05	1.15	0.173	0.56	1.45	2.36	5.12	2.17	Simple	Translation
7	0.196	0.51	1.56	2.46	3.25	1.32	0.174	0.57	1.26	1.41	4.37	3.10	Double	Translation and Rotation
8	0.190	1.92	2.1	3.3	7.45	2.26	0.188	1.65	2.21	3.7	6.74	1.82	Simple	Irregular Changes
9	0.179	2.57	1.58	5.38	9.56	1.78	0.212	1.11	2.42	3.32	5.18	1.56	Cutoff	Cutoff and Redevelopment
10	0.187	1.95	1.4	3.84	11.76	3.06	0.243	0.66	4.17	3.46	4.97	1.44	Cutoff	Cutoff and Redevelopment
11	0.168	0.41	0.86	2.56	3.48	1.36	0.154	1.16	1.1	2.81	3.70	1.32	Cutoff	Cutoff and Redevelopment
12	0.185	0.45	1.15	1.82	3.45	1.90	0.215	0.44	1.83	1.17	3.51	3	Simple	Lateral Movement (Left)
13	0.171	0.75	1.37	1.78	3.58	2.01	0.138	0.69	1.23	1.69	3.85	2.28	Simple	Expansion (Decrease)
14	0.141	0.69	1.15	2.73	3.03	1.40	0.173	0.62	1.01	2.83	3.65	1.29	Simple	Expansion (Decrease)
15	0.248	0.61	1.36	3.66	5.01	1.37	201	0.86	1.34	3.61	4.79	1.33	Double	Extension and Expansion
16	0.175	0.89	1.82	3.52	5.30	1.51	0.168	1.01	1.71	3.42	5.48	1.60	Simple	Expansion (Increase)
17	0.132	0.78	1.45	3.24	4.94	1.52	0.097	0.94	1.54	2.75	4.85	1.76	Simple	Expansion (Increase)
18	0.200	0.50	1.13	3.2	3.81	1.19	0.158	0.63	0.94	2.75	4.01	1.48	Double	Extension and Expansion
19	0.268	0.86	2.56	2.93	5.30	1.81	0.253	0.93	2.05	3.16	4.22	1.97	Simple	Expansion (Decrease)
20	0.172	1.80	2.60	4.59	7.39	1.61	0.170	2.1	2.22	4.7	8.06	1.71	Triple	Extension, Translation and Rotation
Mean	0.194	1.28	1.97	3.65	5.91	1.73	0.176	1.25	2.07	3.35	5.96	1.94		
Min	0.132	0.36	0.86	1.78	3.03	1.15	0.097	0.44	0.94	1.17	3.51	1.29		
Max	0.268	4.47	4.13	7.87	13.23	3.06	0.253	4.65	4.17	8.43	14.09	3.10	----	
SD	0.0367	0.99	0.87	1.46	2.92	0.45	0.0376	0.94	0.94	1.64	2.67	0.59		

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Table 6

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735 Results of paired sample *T*-test for the parameters of the meanders between two dates (1989 and 2008)

Meander parameter	Average difference between variables	Standard deviation	T value	Degree of freedom	Sig.
L	0.2957	0.6144	2.152	19	0.044*
S	0.2385	1.9336	0.552	19	0.588
W	19.9	36.201	2.458	19	0.024*
C	-0.2105	0.6827	-1.379	19	0.184
R	0.0245	0.5075	0.216	19	0.831
A	0.097	0.7108	0.610	19	0.549

736 * Significant at 5% confidence level.

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Table 7

Results of the Pearson correlation between meander parameter changes between 1989 and 2008

Meander parameter	Statistical factor	C	R	W	L	S	A
C	r1	a					
	Sig.						
R	r	0.510*	a				
	Sig.	0.022					
W	r	-0.367	-0.605**	a			
	Sig.	0.111	0.005				
L	r	-0.329	0.479*	-0.219	a		
	Sig.	0.156	0.033	0.353			
S	r	0.725**	0.881**	-0.648**	0.327	a	
	Sig.	0.000	0.000	0.002	0.159		
A	r	0.624**	0.730**	0.641**	0.219	0.919**	a
	Sig.	0.003	0.000	0.002	0.354	0.000	

* Significant at 5% confidence level.

** Significant at 1% confidence level.

[1]Pearson corrélation coefficient.

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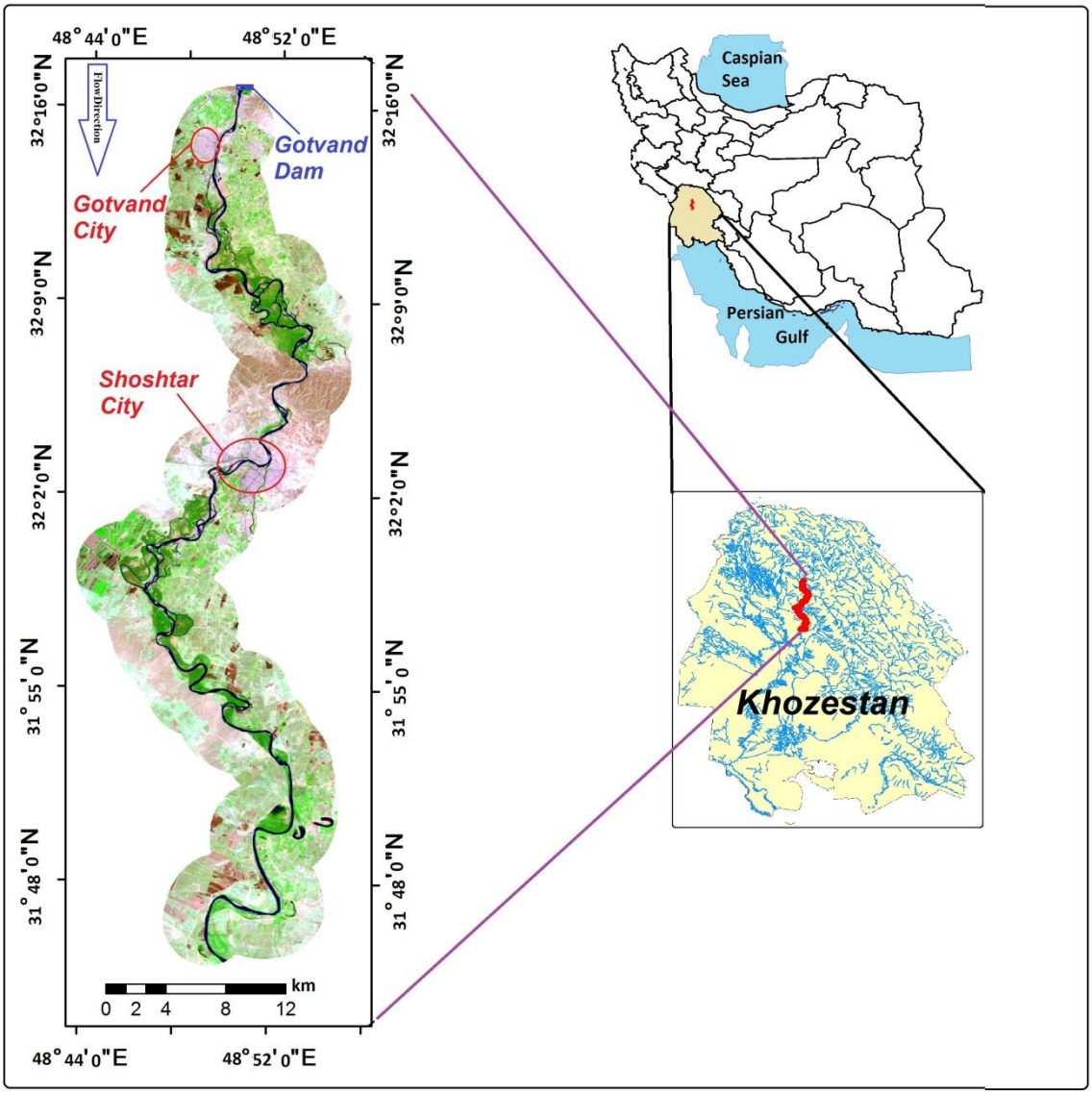
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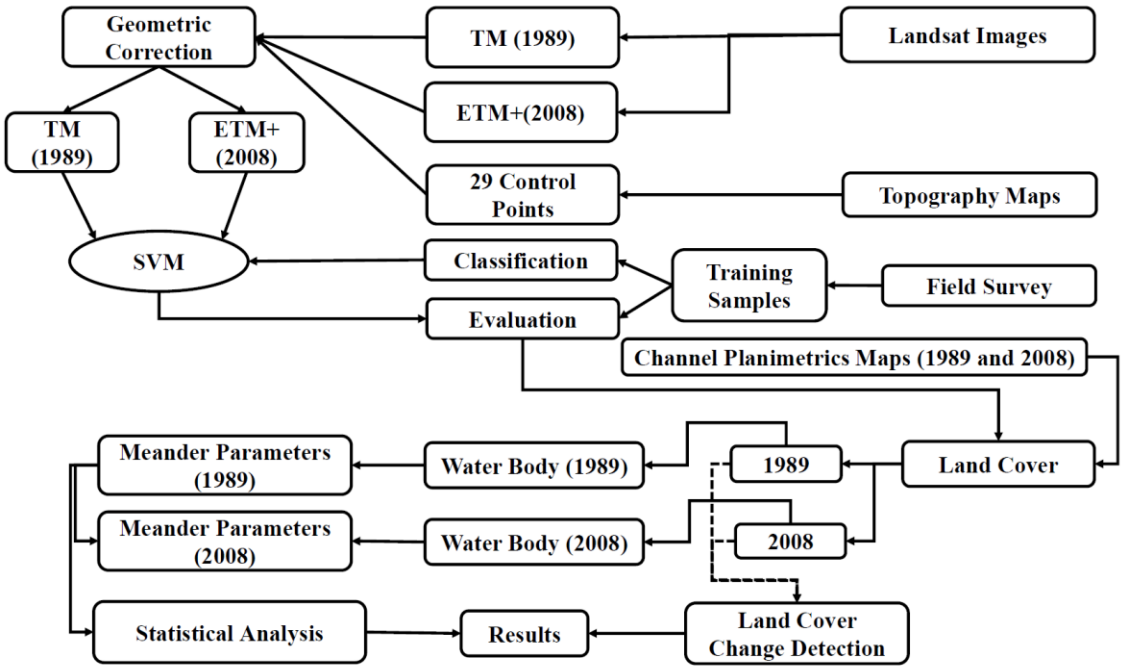
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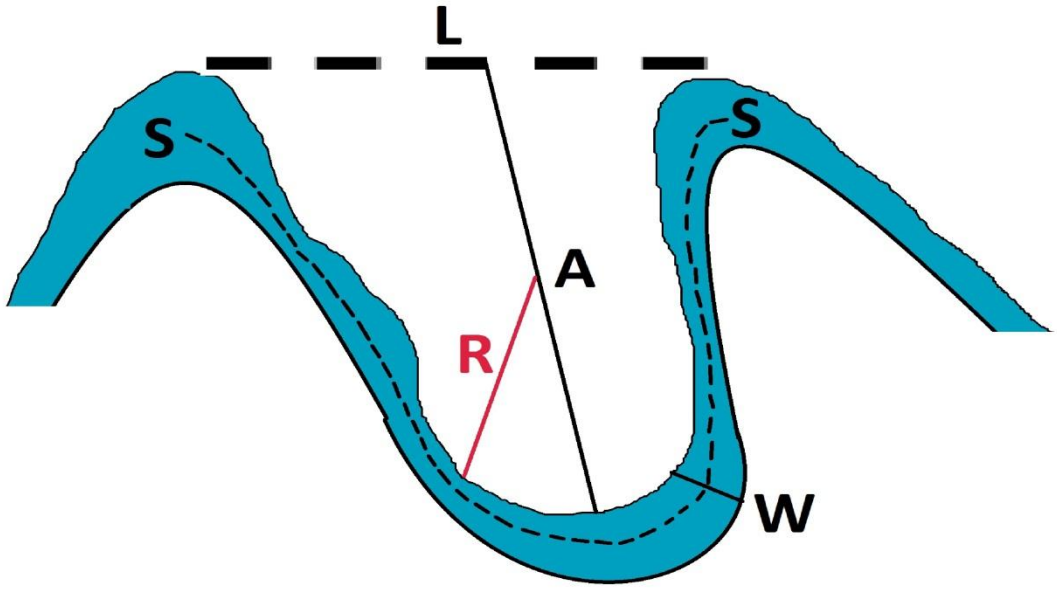
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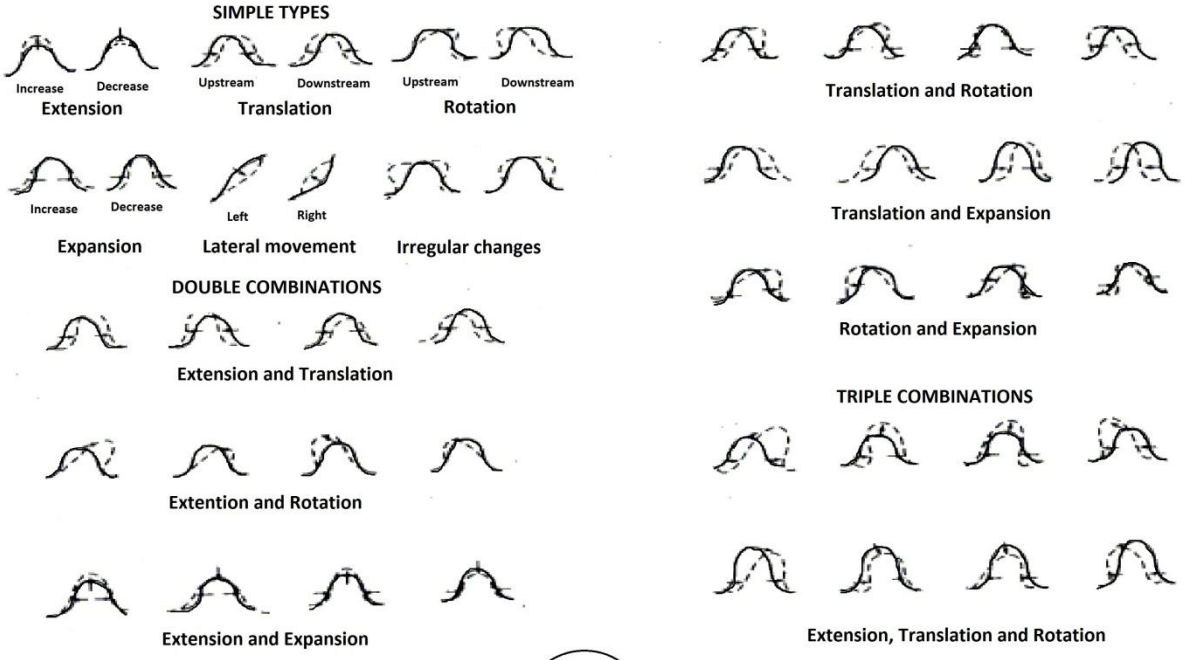
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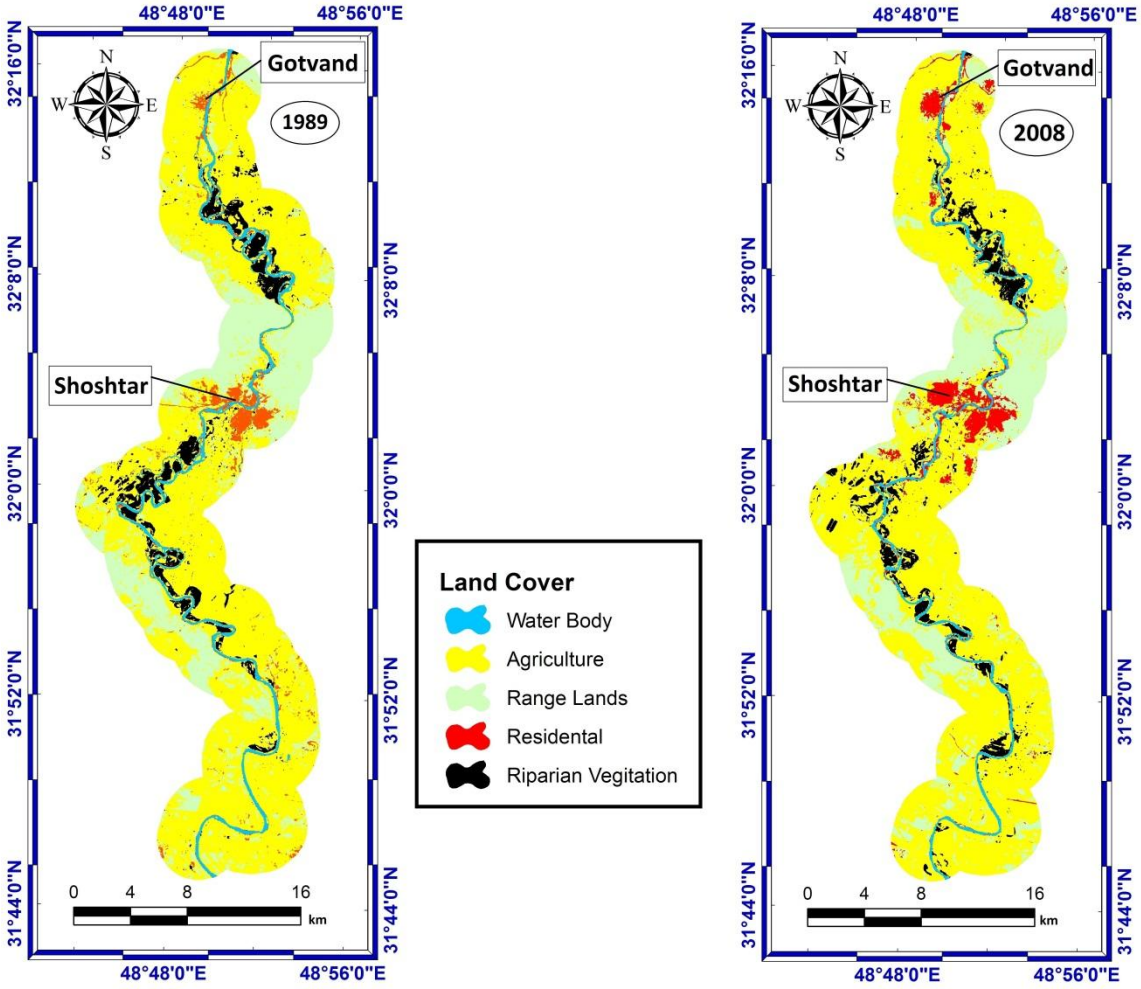

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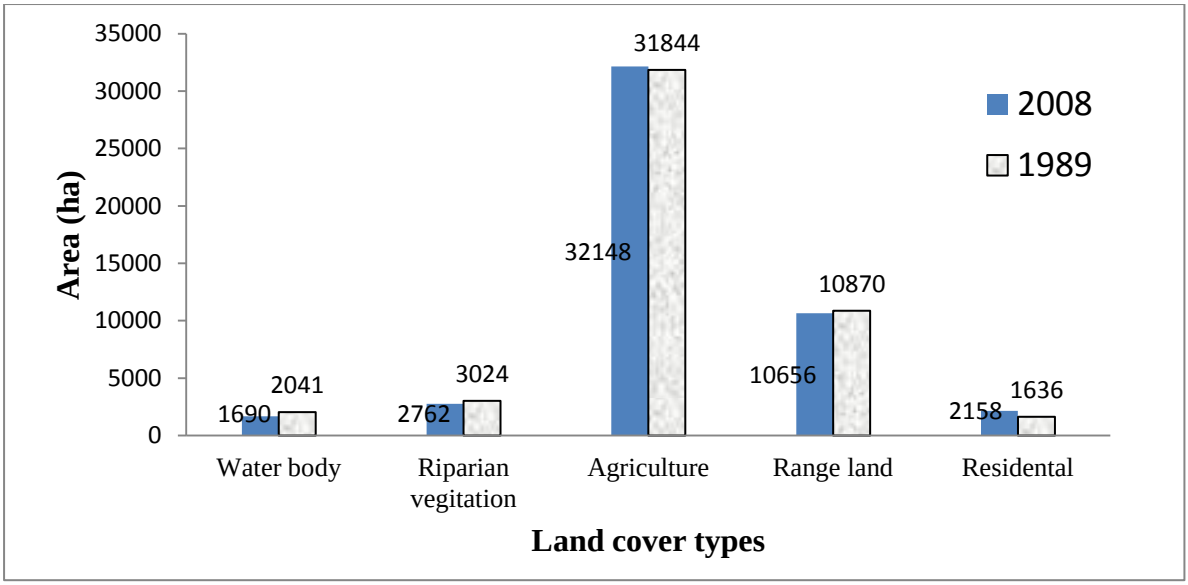
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Riparian vegitation
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Range land
Residental
Land cover types

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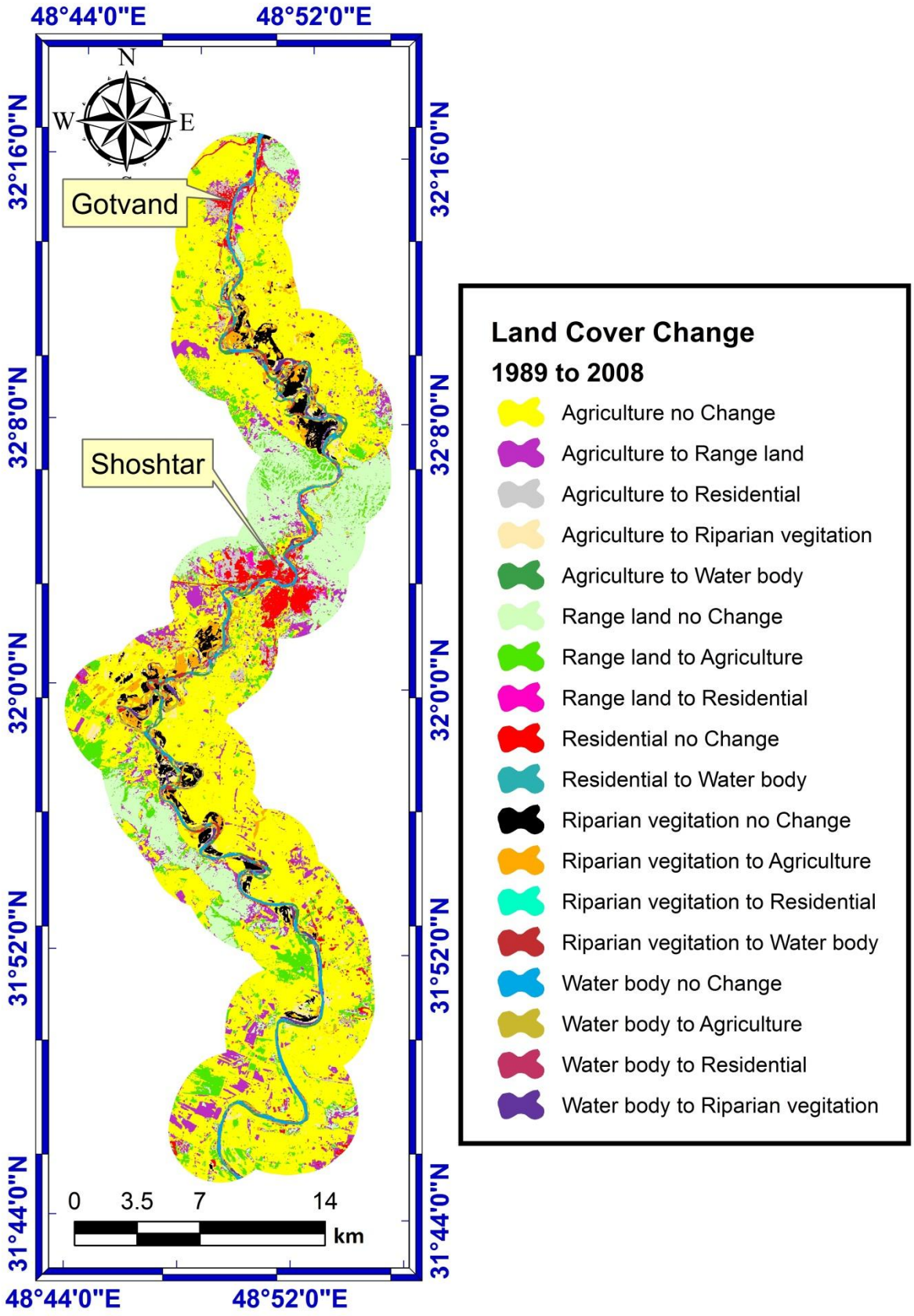
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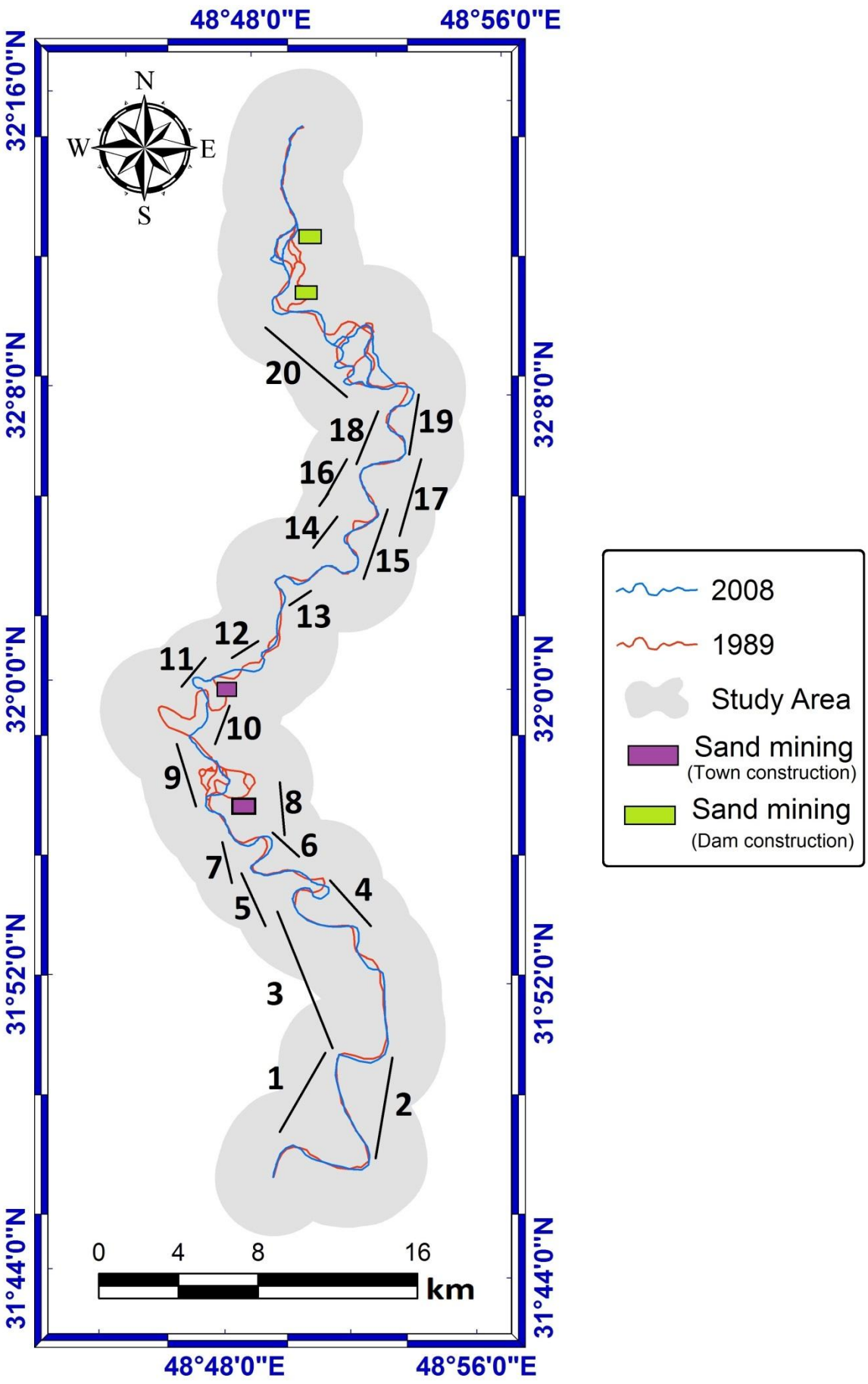
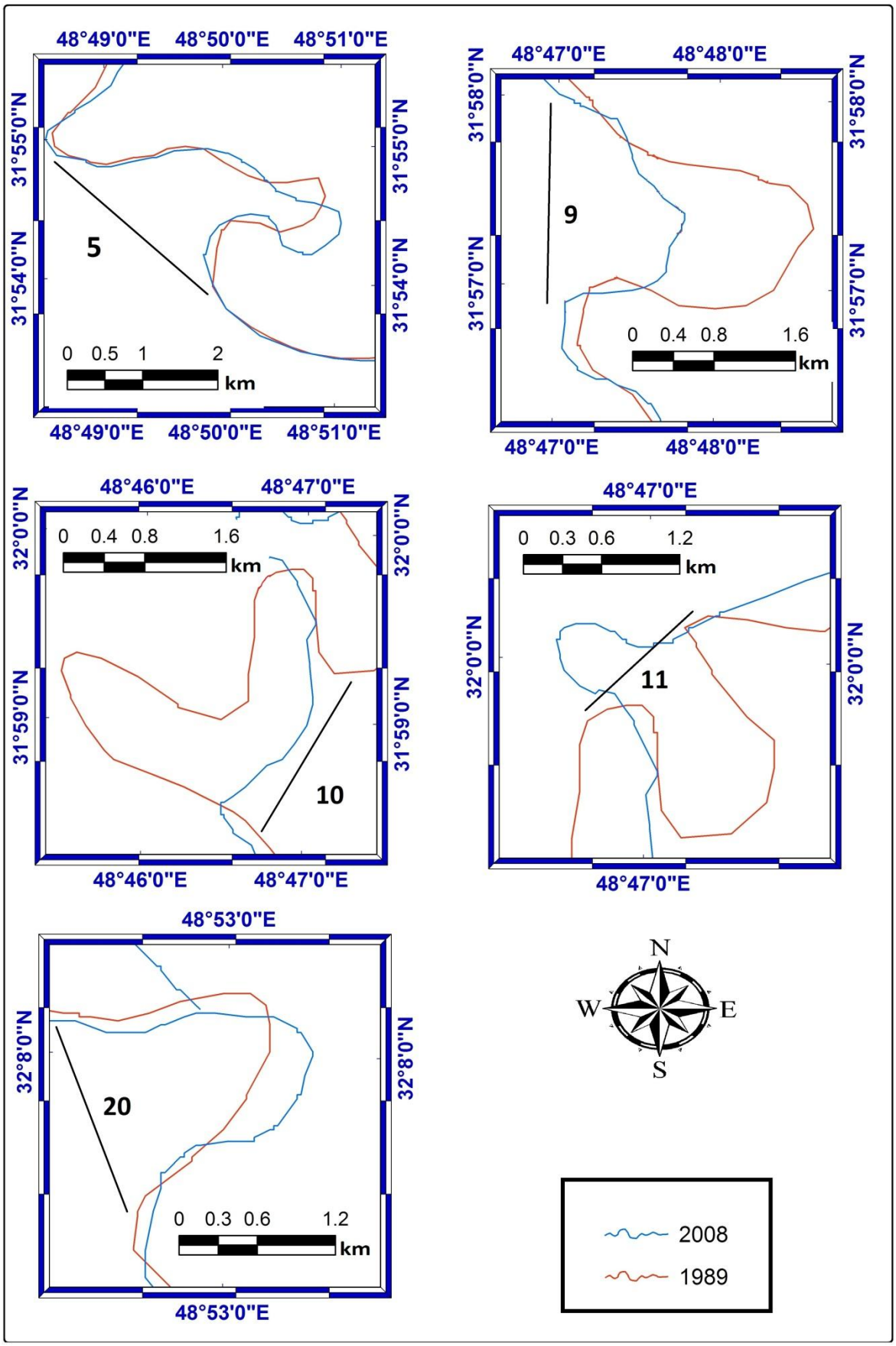
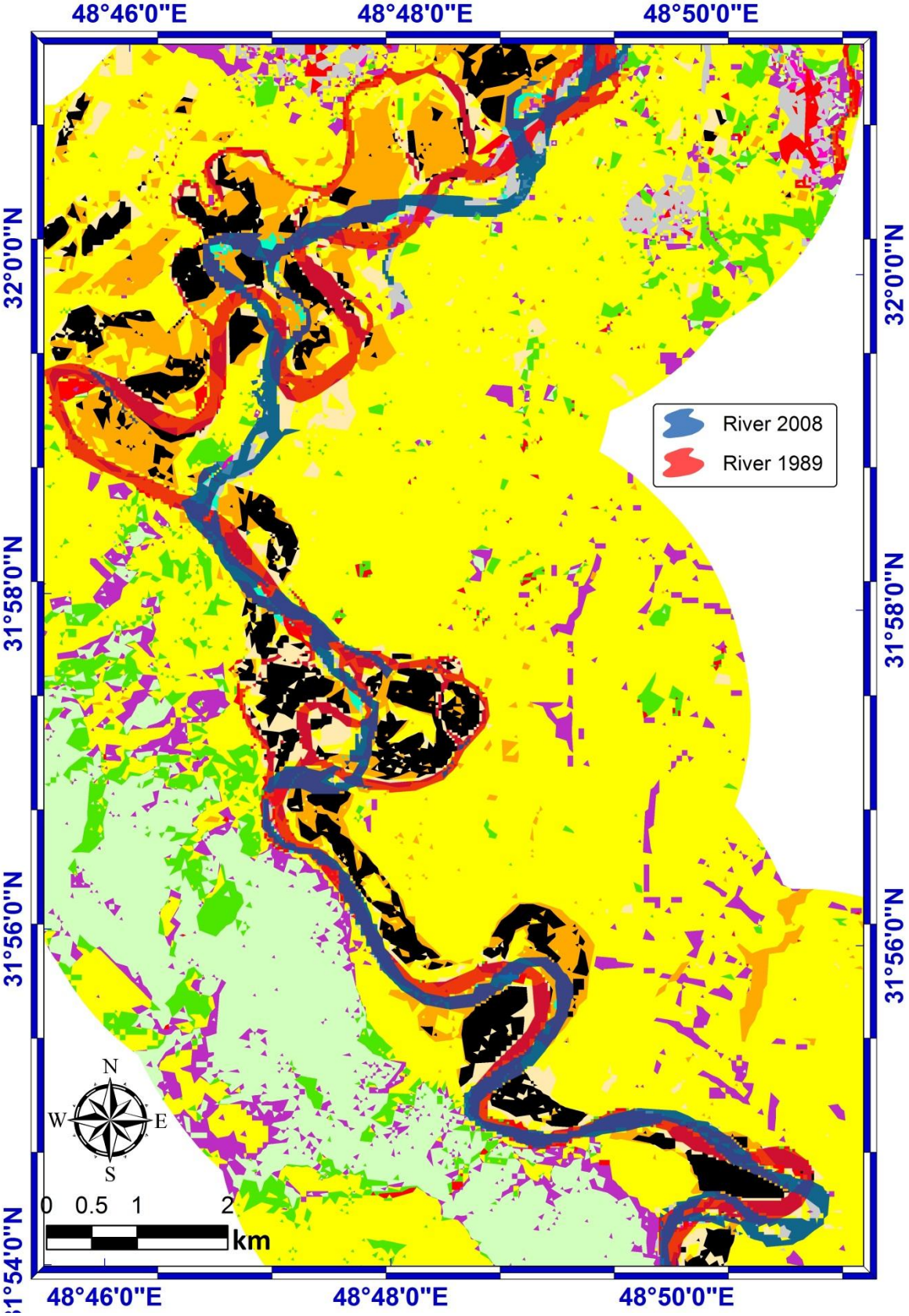
1989 to 2008
Agriculture no Change
Agriculture to Range land
Agriculture to Residential
Agriculture to Riparian vegitation
Agriculture to Water body
Range land no Change
Range land to Agriculture
Range land to Residential
Residential no Change
Residential to Water body
Riparian vegitation no Change
Riparian vegitation to Agriculture
Riparian vegitation to Residential
Riparian vegitation to Water body
Water body no Change
Water body to Agriculture
Water body to Residential
Water body to Riparian vegitation

776


48°48'0"E
48°56'0"E
32°16'0"N
32°8'0"N
32°0'0"N
31°52'0"N
31°44'0"N
N
W
E
S
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
4
8
16
km
2008
1989
Study Area
Sand mining
(Town construction)
Sand mining
(Dam construction)

777


48°49'0"E
48°50'0"E
48°51'0"E
31°55'0"N
31°54'0"N
5
0 0.5 1 2
km
48°47'0"E
48°48'0"E
31°58'0"N
31°57'0"N
9
0 0.4 0.8 1.6
km
48°46'0"E
48°47'0"E
32°0'0"N
31°59'0"N
0 0.4 0.8 1.6
km
10
48°47'0"E
32°0'0"N
0 0.3 0.6 1.2
km
11
48°53'0"E
32°8'0"N
20
0 0.3 0.6 1.2
km
N
W
E
S
2008
1989


48°46'0"E
48°48'0"E
48°50'0"E
32°0'0"N
31°58'0"N
31°56'0"N
31°54'0"N
River 2008
River 1989
N
W
E
S
0 0.5 1 2
km

778
779