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Функціональні значення просторового аналізу в оцінці впливу ґрунтового покриття на прогнозування процесу ерозії

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Ерозія — це процес, що формує земну поверхню, відповідальний за надходження наносів до річкової системи. Виявлення зон, вразливих до ерозії, є критичним елементом управління наносами у водозбірному басейні, що дозволяє оцінити ступінь їх деградації. Дослідження ґрунтувалося на використанні просторових даних, цифрової моделі рельєфу (DTM) і Corine Land Cover (CLC) на прикладі двох водозбірних басейнів, розташованих на нижній течії річки Брда. Основною метою дослідження було оцінити вплив ґрунтового покриття на просторове прогнозування процесу ерозії в масштабі водозбору. Метод максимальної ентропії використовувався для визначення розподілу просторової ймовірності змінних навколишнього середовища, пов'язаних з процесом ерозії. Результати показали найбільшу прогностичну дію особливостей навколишнього середовища, пов'язаних з рельєфом, та з конкретними типами ґрунтового покриття. Прогностичні моделі можна успішно використовувати для прогнозування територій, потенційно схильних до ерозії.

Ключові слова: ерозія; модель максимальної ентропії; передбачення, модель ґрунтового покриття (CLC); просторовий аналіз; водозбір річки Брда.

Надійшла до редколегії 17.11.2022

DOI: <https://doi.org/10.17721/2306-5680.2022.4.3>

UDC 556.537

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WATER EROSION POTENTIAL OF THE CONGO RIVER IN THE STANLEY-POOL BAY

In this paper, a scientific study on the understanding of the erosion and transfer processes of suspended solids or sediments from the Congo River into the Stanley-Pool Bay was conducted. For this purpose, a treatment of rainfall data over three decades (1990-2020), parameters influencing the process of erosive dynamics leading to the realization of the water erosion map using the Universal Soil Loss Equation (USLE), was done. Using open access spatial data and GIS, this USLE model allowed quantifying the rate of material transported over the three decades: a spatialization of erosion risks on the right bank of the Congo River, notably in the Stanley-Pool Bay, a topography dominated by steep slopes up to 10%, a high erosivity and erodibility and a low soil protection were revealed.

Finally, the results of the study show that about 40% of the study area is subject to soil loss. The erosion risk is very severe despite the vegetation cover.

Key words: Solid transport, sediments, modelling, models, Stanley Pool, Congo River.

Introduction. The Congo River is the longest river in Africa (4,700 km) after the Nile, the second longest in the world after the Amazon in terms of flow (41,000 m³s⁻¹) and has a basin area of 3.7 million km² at its mouth. It serves as a border in its upper part between the Republic

ISSN:2306-5680 Гідрологія, гідрохімія і гідроекологія. 2022. № 4 (66)

of Congo (Brazzaville side) and the Democratic Republic of Congo (Kinshasa side) and in its lower part between Angola and the Democratic Republic of Congo (Boma and Matadi) in Bas-Congo. Understanding how it works is therefore crucial in the 21st century when water is a major issue for Africa.

Despite the proliferation of agreements and conventions on the environment (RIO+20 in Brazil), it is difficult, especially for African countries, to follow up on the implementation of the decisions of these conventions at the local level; for example, the desilting of large basins such as the Congo River basin.

Upstream of the two capital cities of the Republic of Congo and the Democratic Republic of Congo, Brazzaville and Kinshasa, lies the Stanley Pool (Mbamou Island), a vast depression 21.4 km long and 12.6 km wide on average, marked in the dry season (from June to August, sometimes until September depending on the year) by imposing sandbanks. Recent scientific hypotheses in the field also highlight the accentuation of erosion problems of an anthropic nature that affect the slopes and banks around the Stanley Pool and in the vicinity of Brazzaville. These problems considerably aggravate the silting up of the navigation channels of the Brazzaville River Port.

Numerous studies carried out at the Stanley Pool in Brazzaville and other scientific documents have shown that the Congo River is increasingly experiencing, in the middle part of its course, active sedimentation due to a significant transport of suspended matter, the volume of which seriously disrupts, in the dry season, port activities at the level of the Ubangi and also at the level of Brazzaville in the bay of the Stanley Pool, and more specifically at the Autonomous Port of Brazzaville. Studies have revealed that river navigation on the Ubangi River has become almost impossible for more than 200 days per year since 2002 due to a longer annual low water period.

In Brazzaville, in the Stanley Pool, at the Autonomous Port, since the extension works undertaken in 1975, this port has been confronted with the problems of sediment deposits (imposing sandbanks) like those of the Oubangui, thus disrupting its river traffic, the only means of transporting people and goods to connect the cities and countries drained by this vast hydrographic network (the Congo River basin). Indeed, solutions must be found because the economic, social and cultural impacts on the local activities of the Port, but also on the hydric and biological balance of the Congo River, are very considerable. Water and soil are a necessary capital for human beings. Soil is a resource that renews itself very slowly (even on a millennial scale) and in semi-arid areas the soil is washed away by water, this is called water erosion [1]. The combined action of rain and runoff sometimes leads to irreversible soil loss, and water erosion is considered one of the causes of soil degradation [2]. On the right bank of the Congo River, for several years silting has disrupted port activity and caused economic disruption. Until now, the Maintenance Joint Service of Waterways of the Autonomous Port of Brazzaville has been dredging in some places to temporarily facilitate traffic.

With a view to finding sustainable solutions, several studies have been carried out: the quantification of matter in the Congo River by Spronck [3], the first to quantify matter in solution (82mg/l), i.e. an export of 106×10^6 tons/year. Symoens [4] quantified the transport of dissolved mineral substances on an annual basis at 46.5×10^6 tons/year in 1968, then 35.5×10^6 tons/year in 1980. In order to refine certain results, during a five-year period (1987 to 1992), the solid and dissolved matter transport of the Congo River was measured monthly at the surface, making it possible to evaluate the solid flow of the river [5]. During this study period, the Congo River had a flow of 37700 m³/s, allowing an average export of 91.8×10^6 tons of material distributed as 7.9×10^6 tons of dissolved matter (DM). The 12% of TSS is made up of particulate organic matter (POM) and 29.5% of dissolved matter (DM). The rest of the load corresponds respectively to particulate mineral matter (88% of TSS) and dissolved matter (70.5% of DM). Compared to the world's major rivers, this interannual average concentration of these transports (76.2 mg/l) is low. Laraque and al. [6] estimate that in this year the Congo River transported 26.3 ton/km²/year with an average runoff of 120 mm [7] and a liquid flow of 41,700 m³/s [8]. The total distribution of this solid transport at the main station of Brazzaville, which controls more than 95% of the total basin area, shows that 30.6×10^6 tons of solids are transported per year. All assessments made on the Congo River at the Stanley Pool were made in a global and sporadic way. Kinga-Mouzeo [9], reiterating earlier results, estimates that the average annual tonnage of suspended exports is 40.56×10^6 tons. Molinier [10] carried out a series of monthly samples from

January 1978 to February 1979. At the same time he tried to diversify the sampling points on the measurement sections. The results of his work are very interesting since they show that the values of the contributions in suspension vary in a significant way between the surface and the bottom, contrary to the dissolved contributions which are approximately identical along a vertical.

Several studies are being conducted to solve this problem without taking into account the relationship between various phenomena, namely (i) water erosion which carries the material into the Congo River, (ii) the different materials transported by the river current according to three modes of transport, (iii) as well as the interaction between the minor bed which is the place of deposition of the suspended material which, when the flow velocity decreases in certain places, is deposited to form sandbanks, and the major bed which transports the material.

This study is a contribution to sustainable solutions for the silting problem in the Autonomous Port of Brazzaville. Using satellite data from the Djiri, Tsieme, Lifoula, la Lefini and BRAZZAVILLE stations, the study uses hydrological modelling (Fig. 1) to estimate the rate of material transported by the Congo River on the right bank over three decades (1990-2020).

MATERIALS AND METHODS

Presentation of the study area. The Congo Basin (Fig. 1), with a length of 4700 km, drains a watershed with a surface area of 3,700,000 km² covering a large part of Central Africa, with a high density hydrographic network and a slope of about 0.033% allowing water runoff.

Several projects have been initiated to understand the hydrological, hydrogeological and hydroclimatic functioning of the Congo Basin [11]. The Stanley Pool at its entrance constitutes a control threshold for the Maluku limnometric station.

At this point in the river, the flow undergoes a variation due to the widening of the straight section of the river. A second natural sill can be observed at the exit of the rapids which controls the scales of the Brazzaville Beach. The surroundings of the Stanley Pool are very permeable to water infiltration, thus characterizing the rich potential of the groundwater in the vicinity of the Stanley Pool; the increasing distribution of clays from the mainland to the river increases a decrease in the permeability of the soil in the vicinity of the Stanley Pool. In the area around the Stanley Pool, where the slab is absent, the sandy plateau and the Stanley Pool sandstone form a thick, permeable mass, which is favorable to the deep infiltration of rainwater.

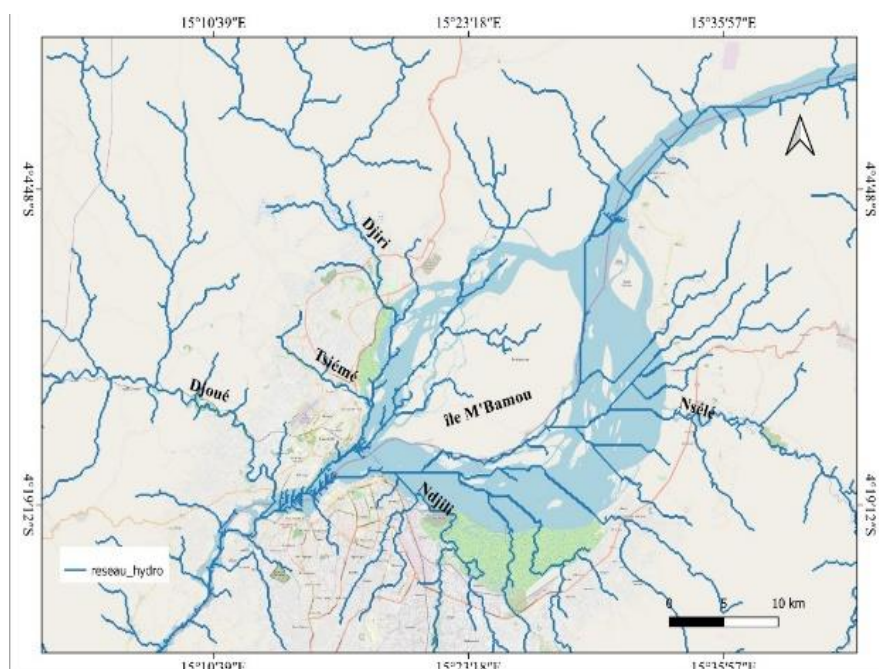


Fig. 1. Hydrographic network of the study area

Materials: data and software used. The data (Table 1) are processed in a multi software platform (Arc Gis 10.4.1 and MS Excel 2010), in order to elaborate a very rich database allowing the manipulation, the update of these data, as well as the visualization.

Table 1. Data and software used

N°	Documents and download platforms Software	Logiciels
1	Digital Terrain Model, Image Shuttle Radar Topography Mission (SRTM) of 30 m resolution of 2014 Obtained from the website : http://srtm.csi.cgiar.org/SELECTION/inputCoord.asp .	Arcgis 10.4.1. MS
2	Carte numérique du sol du monde « Digital soil maps of the world (DSMW), Obtained from the website: http://www.fao.org/geonetwork/srv/en/metadata.show?id=14116	
3	LANDSAT 8 OLI satellite image of 14/08/2019 with 30 m resolution Precipitation recorded at the Brazzaville station between 1990 and 2020 Obtained from the website: https://gis.ncdc.noaa.gov/maps/ncei/cdo/alltimes	Excel 2010

Presentation of the model. Erosion is a multiplicative function of rainfall erosivity (the R-factor which is the potential energy) multiplied by the resistance of the environment, which includes the K-factor (soil erodibility), LS (the topographical factor), C (the vegetation cover and cultivation practices), P (takes into account the anti-erosion practices) These different factors control: climatic aggressiveness, soil erodibility, slope inclination and length, land use and erosion control practices [12 , 13]:

$$A = R \times LS \times K \times C \times P, \quad (1)$$

where: A is the annual rate of soil loss in ton/ha/year, R is the rainfall erosivity factor, K is the soil erodibility, LS is a dimensionless factor representing slope (S in %) and slope length (L in m), C is a dimensionless factor representing the effect of vegetation cover, P is also a dimensionless factor that accounts for erosion control techniques such as contour ploughing.

RESULTS

R-factor. The R-factor (Erosivity in ton/ha/year) is calculated as follows:

$$R = 0.5 \times P \times 1.73 \quad (2)$$

With: P : Annual precipitation in (mm). Using average annual precipitation in (mm) from different regions in and around the study area.

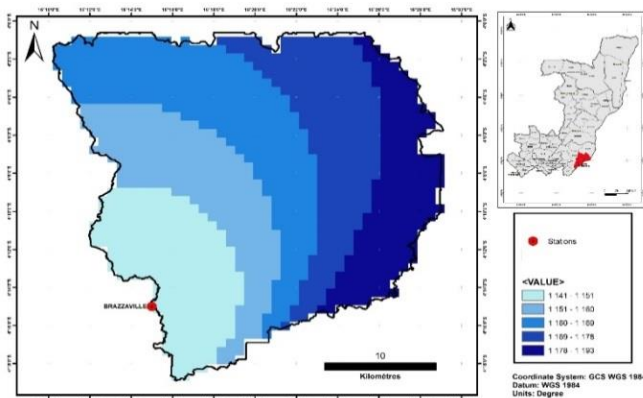


Fig. 2. Rerosivity factor Map

Soil erodibility factor K. The soil erodibility factor K expresses the sensitivity of the soil to water erosion. We evaluated the K index of the different soil types using the equations of WILLIAMS [15] and using the Digital Soil Map of the World (DSMW). Processing this map in ArcGis gave us the rates of different soil types; sand, clay, silt and organic matter. The soil erodibility factor was calculated by the formula of WILLIAMS [15]:

$$FACTORK = f_{csand} \times f_{cl-si} \times f_{orgC} \times f_{hisand}, \quad (3)$$

where: f_{csand} : is a factor that lowers indicator K in soils with high coarse sand content and higher for soils with some sand, f_{cl-si} : gives low soil erosion factors for soils with high rates of silt clay, f_{orgC} : reduces K values in soils with high organic carbon content, f_{hisand} : lowers the K -values for soils with extremely high sand content.

These three equations allowed the calculation of the K-factor, the results are represented. The calculated K values were interpolated using an IDW interpolation method on ArcGIS 10.4.1. The values of the K index in the study area (Fig. 3) range from 0 to 0.1, showing the fragility of the soils susceptible to erosion. The map obtained shows that more than half of the study area represents a high erodibility than the others. The rest of the area has relatively low values of the soil class showing almost no erodibility caused by the forest reserve.

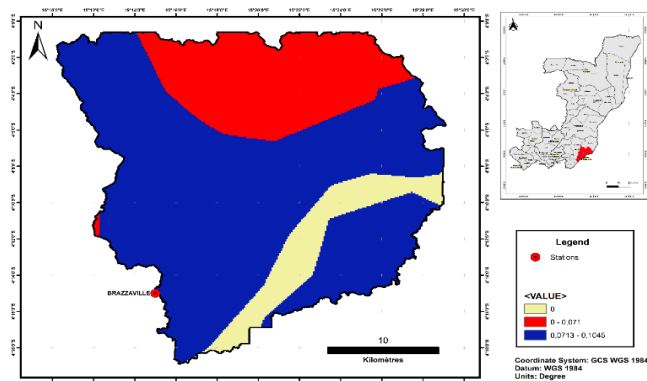


Fig. 3. Erodibility factor Map K

Topographic factor LS. The topographic factor combines the effects of slope length (L) and slope steepness (S) on erosion. These two factors are calculated from the digital terrain model in Arcmap (Eq.4).

$$LS = \left[0.065 + 0.0456 \times (\text{slope}) + 0.006541 \times (\text{slope})^2 \right] \times \left(\frac{\text{slope length}}{\text{constant}} \right)^{NN}, \quad (4)$$

where: Slope = slope inclination (%), Slope length (m), Constant = 22.1 in Sys. Metric (72.5 in Imperial units), NN: see Table 2.

Table 2 : NN Values

Slope	< 1	1 ≤ slope < 3	3 ≤ slope < 5	≥ 5
NN	0,2	0,3	0,4	0,5

The LS factor represents a ratio of soil loss under given conditions, the higher the slope, the greater the risk of erosion. In fact, upstream of the right branch of the Stanley Pool, the slope varies up to 0.1. At these locations, the risk of erosion is very noticeable (Fig. 4).

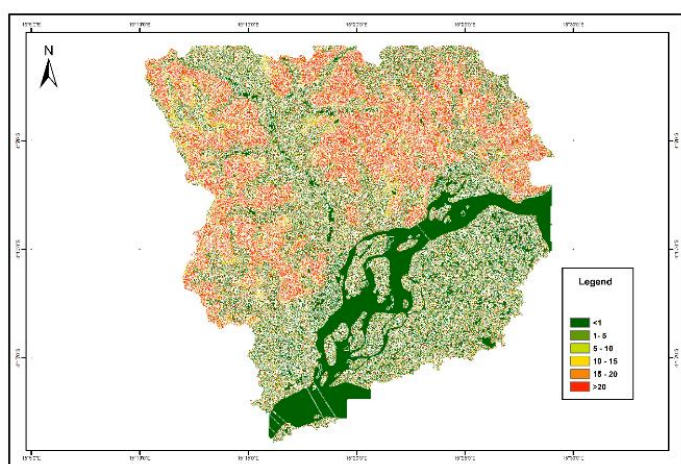


Fig. 4. Topographic factor map LS

Vegetation cover factor C. Vegetation represents the effects of plants, soil cover, soil biomass and soil destructive activities in erosion processes. The determination of this factor is developed from the mapping of vegetation density on a satellite image (LC08 Landsat 8 OLI of 14/08/2019 of 30 m resolution), the latter was analyzed on the Arcgis software platform (version

10.4.1) by calculating the NDVI (Normalized Difference Vegetation Index). Afterwards, we used equation (9) of Van der Knijff et al., [16]:

$$\text{Factor } C = \exp\left(\frac{2 - \text{NDVI}}{1 - \text{NDVI}}\right) \quad (5)$$

The C-factor map, presented in Fig. 5, shows variant values between 0.407 and 1.097. These results show that these values correspond to a better protection of the soils and are favorable for forest formations where anthropic activities are low.

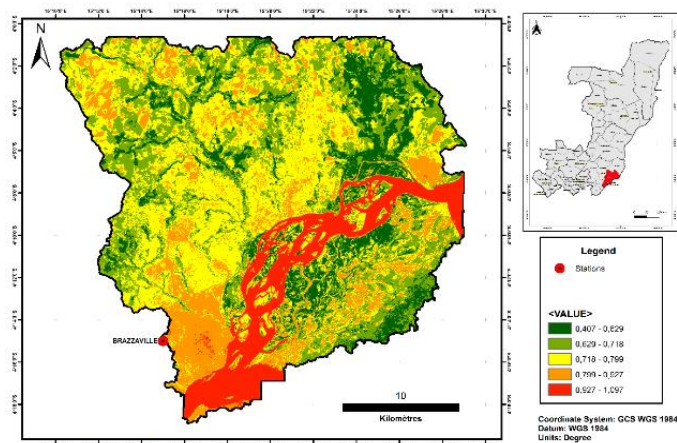


Fig. 5. Vegetation cover factor
Map

Factor of anti-erosion practices P. In the case of the watershed, there are some anti-erosion practices. Thus the factor P, referring to the reality of the field thanks to satellite images and the map in Fig. 6, has been assumed to be equal to 0.8. This map (Fig. 6) shows that about 60% of the study area is relatively protected while the rest is exposed to very high water erosion risks.

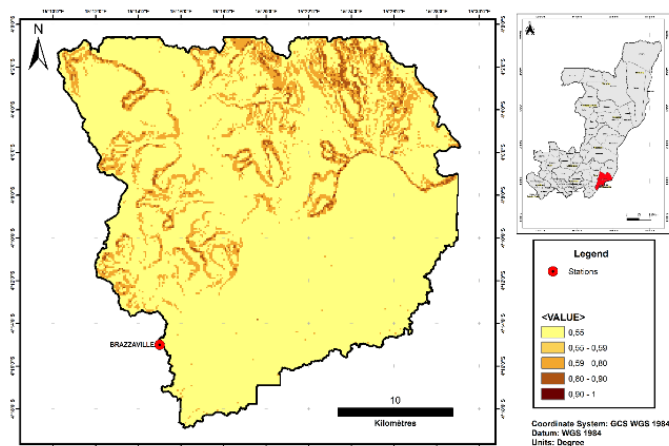


Fig. 6. Map of erosion control practices

Water erosion rates. The multiplication of the different USLE parameters under ArcGis software is given by:

$$\text{Water erosion rate} = R \text{ factor} \times K \text{ factor} \times LS \text{ factor} \times C \text{ factor} \times P \text{ factor} . \quad (6)$$

The simulation yielded the erosion risk map (Fig. 7), informing on the erosion potential in t/ha/year per spatial unit (DTM pixel) at a few points of the watershed with values ranging from 0 to 1381 tons/hectares/year. This map shows a clear spatial variability of water erosion risks within the study area. The right branch of the Congo River, which is a final spillway of the hydrographic network of the city of Brazzaville, is one of the causes.

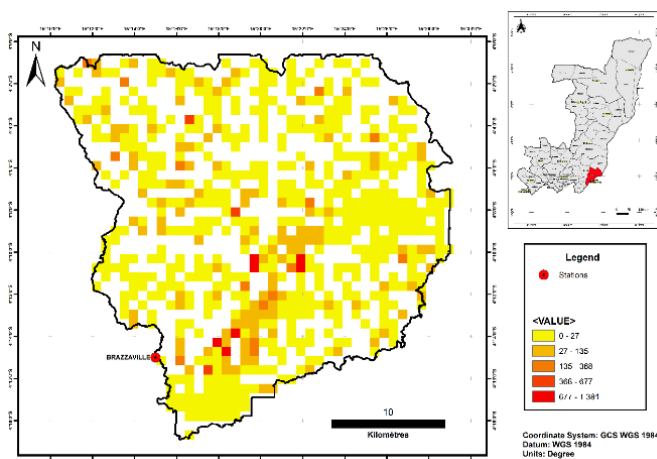


Fig. 7. Soil loss map in (tons/ha/year) in the Watershed

Conclusion. This study is based on the use of open access spatial data and GIS for a spatialization of erosion risks on the right bank of the Congo River, particularly in the Stanley-Pool bay which is the study area. It showed that in this area of the Congo River, the topography is dominated by steep slopes up to 10%, the erosivity is high, the erodibility is high and the soil protection is low. In addition, the existence of an urban and agricultural area in the steep slope zone accentuates the risk of erosion at this location. The results of this study show that approximately 40% of the area is subject to soil loss. The risk of erosion is very severe despite the vegetation cover.

The good management of the hydrographic network, the methods of soil survey by the installation of grass strips are better adapted to face the risk of erosion in this zone, the afforestation of the zones with weak vegetation cover and the support of the efforts undertaken by the population will make it possible to protect in a durable way this territory.

The use of the USLE model, GIS techniques and open access multi-source data can be applied at a reasonable cost to map the risk of erosion at the territorial scale, the analysis of the variability of erosion intensity and the identification of priority areas for soil conservation in the Republic of Congo.

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Потенціал водної ерозії річки Конго в затоці Стенлі-пул

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У цій статті проведено наукове дослідження розуміння процесів ерозії та перенесення завислих твердих речовин або осадів із річки Конго в затоку Стенлі-Пул. З цією метою було виконано обробку даних про кількість опадів за три десятиліття (1990-2020), параметрів, які впливають на процес ерозійної динаміки, що обумовило створення карти водної ерозії за допомогою універсального рівняння втрат ґрунту (USLE). Використовуючи просторові дані відкритого доступу та ГІС, ця модель USLE дозволила кількісно визначити швидкість транспортування матеріалу протягом трьох десятиліть: розподіл ризиків ерозії на правому березі річки Конго, зокрема в затоці Стенлі-Пул, в рельєфі якої переважають круті схили до 10%, виявлено високу ерозійність та еродованість та низьку ґрунтозахищеність.

Нарешті, результати дослідження показують, що близько 40% досліджуваної території піддається втраті ґрунту. Ризик ерозії є дуже великим, незважаючи на наявність рослинного покриву.

Ключові слова: перенос твердих речовин, відкладення, моделювання, моделі, басейн Стенлі, річка Конго.

Надійшла до редколегії 19.11.2022

DOI: <https://doi.org/10.17721/2306-5680.2022.4.4>

UDC 556.532.5:519.8

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APPLICATION OF HEC-RAS MODEL TO ANALYZE OF SEDIMENT TRANSPORT DYNAMIC PRE AND POST CONSTRUCTION OF FALL STRUCTURES AT LOWER NARA CANAL OFF-TAKING FROM UPPER NARA CANAL, SUKKUR BARRAGE, INDUS RIVER, SINDH, PAKISTAN

This paper presents the research study using the HEC-RAS model to evaluate sediment dynamic problems in lower Nara canal pre and post-construction of fall structures at RD-77 and 101 respectively which is a major tributary of upper Nara canal that off-takes from Sukkur barrage on the left bank of Indus River. As a result, the hydraulic model has computed longitudinal and cross-section, velocity, water surface profiles, and sedimentation dynamics. Sediment transportation without fall structure is aggradation (5.75 ft and degradation (4.50 ft) and with fall structure aggradation (4.25 ft) and degradation (2.75 ft) respectively. Sediment transportation without fall structure is aggradation 500,000 tons and degradation 225,000 tons and with fall structure aggradation 155,000 tons and degradation 125,000 tons. Sediment transportation without fall structure is degradation 600,000 tons and with fall structure is aggradation 110,000 Tons and degradation 165,000 Tons. Sediment transportation without fall structure is aggradation 1,750,000 Tons and with fall structure is aggradation 1,300,000 Tons. Hence the results of the model revealed that aggradation at u/s and degradation at d/s of fall structures that is a true representation of the behavior of fall structures. Whereas, the section is wider than aggradation occurred and degradation is experienced in narrow sections in both scenarios (with and without fall structures). The positive impact of constructed fall structures was analyzed on the morphology of the canal. Hence, the construction of fall structures are essential at the change of country/steeper slope to avoid unnecessary erosion.

Key words: HEC-RAS model, lower Nara canal, Indus River, fall structure, sediment transportation, aggradation degradation.

ISSN:2306-5680 **Hydrology, Hydrochemistry and Hydroecology. 2022. № 4 (66)**